AR-009-421

DSTO-RR-0059

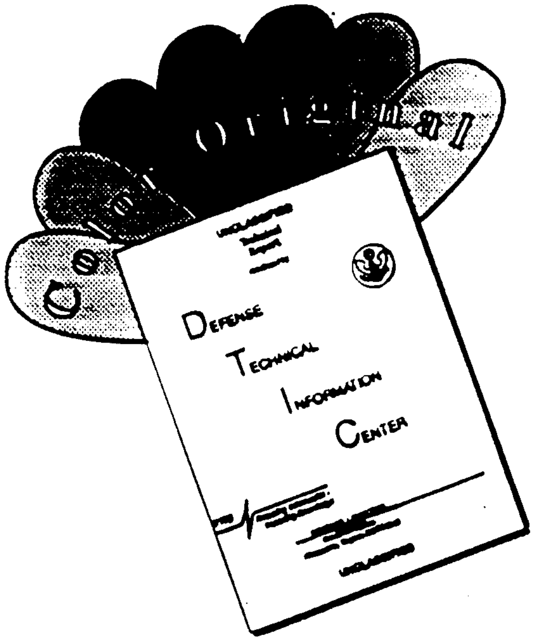
Round-The-World High Frequency Propagation: A Synoptic Study

Mark A. Tyler

APPROVED FOR PUBLIC RELEASE

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF COLOR PAGES WHICH DO NOT REPRODUCE LEGIBLY ON BLACK AND WHITE MICROFICHE.

Round-The-World High Frequency Propagation: A Synoptic Study

Mark A. Tyler

High Frequency Radar Division
Electronics and Surveillance Research Laboratory

DSTO-RR-0059

ABSTRACT

This Report presents the results of a synoptic study of the propagation characteristics of round-the-world (RTW) high frequency radio signals. The observations were made near Alice Springs using a backscatter sounder. The diurnal, seasonal and solar cycle variations in the signal power and frequency limits are discussed. The measured optimum direction of propagation is determined and compared to a simple model.

RELEASE LIMITATION

Approved for Public Release

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Published by

DSTO Electronics and Surveillance Research Laboratory
PO Box 1500
Salisbury. South Australia, Australia 5108

Telephone: *(08) 2597073*
Fax: *(08) 2596673*

AR-009-421
September 1995

APPROVED FOR PUBLIC RELEASE

Round-The-World High Frequency Propagation: A Synoptic Study

EXECUTIVE SUMMARY

Round-the-world (RTW) propagation of high frequency (HF) radio waves has been observed since 1927. Results of a synoptic study of this phenomena using the backscatter sounder that is part of the Frequency Management System of the Jindalee Over-the-Horizon radar are presented. The diurnal, seasonal and solar cycle variations in the signal power and frequency limits are discussed.

In winter RTW signals were exclusively observed during the daylight hours. In summer there were two periods when RTW propagation was observed. There was a primary period when strong signals were detected commencing at sunset and which lasted for up to 6 hours. Weaker signals were also observed during the middle period of the day. The frequency extent of the RTW signals was from 9 to 21 Mhz during winter and 9 to 24 Mhz in summer. A significant asymmetry was noted between the equinoxes. The frequency limits during the autumn equinox were measured to be 3 to 5 Mhz greater than those during the spring equinox. Some evidence of solar cycle variations was seen in the data. After taking into account the diurnal and seasonal variations both the received power and frequency extent of the RTW signals decreased with decreasing sunspot number. The optimum direction of propagation during both summer and winter was examined and found to closely fit the simple model proposed by Fenwick [1963].

Any long range echoes, like RTW, have the potential to mask wanted target signals for an OTH radar. The frequency band between 11 and 21 MHz where the RTW signal is observed is also one of the most useful for OTH radar operations. An evaluation of the impact of these signals on radar target detection capability requires an estimate of the Doppler characteristics of the echoes which has not been systematically studied. The fact that RTW signals occupy a relatively small range depth means that it should be possible to develop mitigation strategies that minimise any negative impact.

THIS PAGE INTENTIONALLY BLANK

Author

Mark A. Tyler
High Frequency Radar Division

Mark Tyler is a Professional Officer in the Ionospheric Effects Group of High Frequency Radar Division. He graduated from the James Cook University of North Queensland in 1985 with a Bachelor of Science degree and was awarded a Master of Science degree in 1988.

He joined DSTO in 1988 and has worked in the areas of radar performance estimation, round-the-world propagation and HF surface wave radar modelling.

THIS PAGE INTENTIONALLY BLANK

Contents

TABLE OF FIGURES

THIS PAGE INTENTIONALLY BLANK

1. Introduction

1.1 The Impact of Round-the-World Propagation on OTH Radar

The Jindalee Over-the-Horizon (OTH) radar transmits high frequency (HF) radio waves that are reflected by the ionosphere. They are used to detect and track targets at ranges of 1000-3000 km from the radar.

The Jindalee radar uses a waveform that is repeatedly transmitted tens of times per second. The repetitive nature of the signal means that interference from ranges much greater than the radar's region of interest can wrap down into the operational region. Long range clutter with large Doppler offsets or spreads can mask the wanted target signals in the radar returns. Thus it is important to determine characteristics of such phenomena and their impact on the radar.

The HF band is also where the phenomena of round-the-world (RTW) propagation takes place and thus there is the potential for the RTW signals to interfere with the radar's ability to detect targets. The characteristics that are important for radar work are the magnitude and frequency behaviour of the RTW signals, including any diurnal and seasonal variation. A program of measurements was undertaken to try to understand these factors. Although the Doppler spread on the RTW signal is also an important factor for radar work as this determines the proportion of targets that may be obscured, this is beyond the scope of this report.

1.2 Round-the-World Propagation: Previous Measurements

The phenomena of extremely long range and round-the-world propagation was first reported by Quack [1927]. He investigated Morse code signals from a shortwave transmitter in the United States operating at 18.55 MHz. When received in Germany they were also accompanied by a second, weaker signal. This second signal was delayed by a short time and was attributed to an alternative, longer propagation path in the reverse direction encircling the earth. He also reported cases where the delayed signal had travelled around the entire circumference of the earth. These latter signals were dubbed round-the-world echoes and were found to have delays of between 135 and 138 milliseconds.

Further work, Quack and Mogel [1929], established that the most favourable conditions for round-the-world propagation occur when the signals propagate along the line of twilight around the earth. Some attempt was also made by these workers to characterise the temporal behaviour of the phenomena. Hess [1948] showed further measurements that indicated RTW signals propagated during the daylight hours in winter and after sunset in summer.

There were two possible RTW propagation mechanisms discussed by Hess. In the first theory the radio wave was reflected multiple times, at low angles of incidence, from the ionosphere and the earth's surface. It was calculated that between 12 to 17 hops were required to complete the circuit. The second explanation relied on a "sliding wave" that travelled at a constant height in the ionosphere. The ray would constantly leak energy out as it propagated and this would be detected at the ground.

The currently accepted theory of RTW echo propagation was developed by Fenwick [1963]. This states that the propagation in the sunlit hemisphere is via standard E or F mode hops from earth to ionosphere and back. However, for the night hemisphere part of the journey, the radio wave is reflected from ionosphere to ionosphere (primarily F-layer reflections) with no intervening contact with the ground. The transition between the two types of propagation arises due to the effect of the steep gradients in the ionosphere at the sunset and sunrise boundaries. These gradients allow rays to achieve the correct angles to enter and leave the whispering gallery mode of propagation.

Experiments to test this theory were carried out by Fenwick and Villard [1963a]. They showed that a round-the-world signal was simultaneously undetectable at a receiver on the ground in the dark hemisphere while being observed by another receiver in the daylight hemisphere. These observations support the Fenwick theory for the propagation mechanism. Ray path modelling work based on geometric optics was reported by Grossi and Langworthy [1966]. They showed how the presence of the gradients in the ionosphere due to sunrise and sunset could allow rays to enter and leave the whispering gallery mode of propagation.

An interesting point noted by a number of authors including Isted [1958] was that the time delay for RTW propagation was independent of transmission frequency and would only vary by 1-2% from a mean of about 138 milliseconds. The time delay was also unaffected by diurnal, seasonal and solar cycle variations. This is in sharp contrast to the time delay of normal one or two hop propagation which is strongly influenced by all of these factors.

The relatively small dispersion on the RTW signals is also important. Fenwick and Villard [1963b] presented results of the received RTW pulse width as a function of transmission frequency. A pulse of width 1 millisecond was transmitted at a range of frequencies. The receiving system introduced broadening of approximately 1 millisecond to the pulse width. The received RTW pulses had widths that ranged from 6 or more milliseconds at 12 MHz down to about 2 milliseconds at 24 MHz. This broadening was attributed to the presence of a number of propagation paths resulting from the transmission of rays of different elevation angles.

Bubenik et al. [1971] have described observations of fine structure related to multiple modes of RTW propagation. Hooklike structures were visible on RTW ionograms and these showed similarities to the shape of the nose of oblique ionograms recorded near the receiving site.

A comprehensive review of the experimental and modelling work in round-the-world propagation has been published by Toman [1979]. The monograph by Gurevich and Tsedilina [1985] also has a long list of references that covers the work done in Russia and east European countries.

2. Round-the-World Propagation

2.1 Measurements at Alice Springs

A backscatter sounder was used to make the RTW measurements described in this document. It is a part of the Frequency Management System (FMS) of the Jindalee Over-the-Horizon-Radar. The various sub-systems of the FMS have been described in detail by Earl and Ward [1987].

The FMS backscatter sounder is normally used to measure the propagation conditions across the HF band for ranges from 0 to 12000 kilometres over a number of azimuths. A 10 kW transmitter located at Harts Range, 100 km to the north-east of Alice Springs, feeds a single log periodic antenna oriented to the north-west. An FMCW signal, swept from 5 to 45 MHz, is transmitted and a synchronised receiver is used to detect the backscattered energy. The receiver site is located at Mount Everard, 40 km north-west of Alice Springs. A linear antenna array allows eight simultaneous receiver beams to be formed covering the 90° sector from west to north (from 279° to 9° East of North). Figure 1 shows the standard FMS beams labelled 0 through 7.

Each backscatter ionogram is measured at a frequency resolution of 200 kHz from 5 to 45 MHz. The time delay resolution is 0.325 milliseconds and 256 delay cells are recorded covering approximately 80 milliseconds of delay space. An example of a single backscatter ionogram recorded on Saturday 2nd April 1994 on beam 5 is shown in

Figure 2. There is strong 1 and 2 hop propagation between and 0 and 50 milliseconds delay up to 32 MHz for this particular time. Beyond this delay there is no detectable backscattered power. Note the calibration signal at a level of -122 dBW which is injected at 80 milliseconds delay for all frequencies.

To record standard backscatter ionograms the transmitter and the receiver are synchronised such that they are tuned to the same frequency simultaneously. This ensures that the ionograms cover ranges from 0 to 12000 km. However it is possible to put a delay between the transmitter and the receiver so that signals that have travelled once around the world lie within the receiver passband. This delay is variable in 1 microsecond steps from 0 milliseconds delay but is normally set to 80 milliseconds for RTW measurements. For an offset of 80 milliseconds the time delay coverage is from 80 to 160 milliseconds.

For standard backscatter ionograms the receiver antenna array detects the scattered energy from the forward direction via the main lobes of the beam patterns. However in the RTW case the signal is received through the back lobes of the array. Figure 1 shows the beam directions for the standard backscatter and RTW configurations. The standard backscatter sounder beams are labelled 0 to 7 with beam 0 being the western-most beam and beam 7 the most northerly. The coverage is 90 degrees with boresight at 324 degrees east of north. The beam width of the receiving beams varies with frequency and is given by

$$BW = \frac{120}{F} \qquad 1$$

where BW is the half power beam width in degrees

F is the frequency in MHz.

The beams are centred 11.5 degrees apart across the 90 degree coverage. For the RTW case the beams are labelled from beam 0 which covers the north-south path around to beam 7 which covers the east-west direction.

2.2 Round-the-World Ionograms

A typical RTW ionogram recorded using the backscatter sounder is shown in Figure 3. This ionogram was recorded 20 minutes prior to the standard backscatter ionogram of Figure 2. Nominally one set of eight round-the-world ionograms covering all FMS beams is recorded every hour. There are a number of distinctive features of the RTW echoes -

i) The RTW signal is generally the only non-noise feature visible from 80 to 160 milliseconds delay.

ii) The clutter is localised in delay at approximately 138 milliseconds with a width of 2 to 6 milliseconds. Also the time delay of the signal peak is approximately constant over frequency. This contrasts with the backscatter ionograms which show a significant increase in time delay with increasing frequency.

iii) The peak RTW clutter power is comparable to the backscatter clutter power of Figure 2.

iv) The frequency range of the RTW propagation is reduced compared to the backscatter sounding at a similar time. It has both a higher lowest useable frequency (LUF) and a lower maximum useable frequency (MUF) than for the one hop F-layer trace.

v) There is an preferred direction for RTW propagation as evidenced by higher signal levels on some beams. This optimum direction varies during the day.

An example of the variation of RTW propagation with beam is shown in Figure 4. This shows the 8 RTW beams recorded at 00:15 Universal Time (09:45 Local time) on Saturday, April 2nd 1994. The RTW ionogram shown previously in Figure 3 can be seen here in beam 5. The clutter is quite strong in the north-west to south-east propagation direction (RTW beams 4 and 5). Around to the east-to-west and north-to-south directions (RTW beams 0 and 7 respectively) RTW clutter is almost entirely absent.

Four hours later at 04:15:10 UT, Figure 5, the direction of maximum RTW propagation has moved to beam 7. The RTW signals that are visible on beams 0 and 1 are due to energy received via the array sidelobes. The level of sidelobe suppression is approximately 20 dB below the main beam level. No effort has been made to remove sidelobe contamination from the data presented in this report.

2.3 Analysis Technique

Before any analysis was done, the ionograms were processed to identify and isolate the RTW signal. This cleanup procedure was an automatic process that was applied to every ionogram. Figure 6 shows an example of a cleaned up ionogram that corresponds with the raw RTW ionogram in Figure 3. Note that, as well as removing the background noise, the signal at each frequency has been normalised to a nominal 1 kW of transmitted power. This has meant the apparent signal strength has been reduced by up to 8-10 dB at some frequencies because the backscatter sounder transmitter radiates significantly more than 1 kW in some bands.

The cleaned up ionograms were then analysed in monthly blocks. A number of parameters were scaled from each ionogram between 135 and 145 milliseconds delay for each run of the month. These delay limits were chosen to reduce the possibility that spurious signals surviving the cleanup process could influence the results. It was possible

to examine such a limited bracket of delays because the round-the-world signal is so well defined in time delay. The parameters that were scaled are -

i) Minimum frequency of RTW propagation.

ii) Maximum frequency of RTW propagation.

iii) Frequency span. This is the difference between i) and ii).

iv) Maximum clutter power in the RTW trace, independent of frequency.

v) Frequency at which the maximum clutter power was found.

vi) Area of the ionogram occupied by the RTW signal. This is a count of the number of pixels which are characterised as belonging to round-the-world signal.

Thus for each hour in each day of the month being processed, eight values (one for each beam) were recorded for each of the scaled parameters. Once the data had been processed in this way it was possible to examine the temporal and seasonal characteristics of the RTW signals.

3. Results

3.1 Temporal Variation of RTW Propagation

To examine the diurnal variation of RTW propagation a month of summer and a month of winter data in 1993 was chosen. Because the transmitter and receiver sites are in the southern hemisphere the winter month is June 1993 and the summer month is December 1993.

3.1.1 Summer RTW Propagation

The maximum clutter power from RTW ionograms for each day in December 1993 is illustrated in Figure 7. The clutter power in dBW is plotted as a colour image with day of the month on the x-axis. The time of day is plotted on the y-axis at one hour resolution, the left hand scale is universal time and the right hand scale is local time at the receiver site. Within each day on the x-axis are eight columns representing the values of the peak clutter power for each of the eight beams. Beam 0 is the leftmost value within each day.

If on any beam there is no detectable RTW signal then a grey entry is printed. When there is no RTW ionogram is recorded, due to operational requirements, system failures etc., a blank entry is plotted for that hour. Also shown on the figure are lines representing the times of sunrise and sunset at ground level at the receiver site. The lower line marks sunset and the upper one, sunrise.

A smaller plot to the right of the main figure shows the statistics of the clutter power for the month. The lower decile, median and upper decile values for each hour and beam are plotted. Again the values for each beam are plotted within each column. In order to generate statistically significant decile values a threshold number of measurements in each hour was set. A median value for an hour was calculated if there was data for at least three days during the month. The decile values require hourly measurements on at least ten days during the month for each hour. If there are not sufficient values to calculate a statistic for an hour a blank entry is plotted.

In December 1993 there were strong RTW signals that became established at local sunset with a dramatic increase in the maximum clutter power at the time of the evening terminator. Over the course of the following 4 to 5 hours the maximum clutter power decreased until the RTW signal disappeared below the noise floor at about 1500 UT (0030 LT). This event could be observed every day with the only variation being the strength of the echoes.

There was a secondary period when the RTW signals were detected during December. During the daylight hours commencing at around 0000 UT (0930 LT) RTW propagation was seen but with maximum clutter powers that were at least 20 dB less than the post-sunset propagation. The daylight signals could be seen to last right up until sunset on some days (e.g. 24th December) while on others (e.g 26th December) they were barely detected at all. This increased variability in the detection of this second type was due to the variation in the amplitude of the RTW signal. Once the signal to noise ratio became too low detection of the round-the-world echoes became impossible.

The optimum direction of RTW propagation can be deduced from the distribution of the maximum clutter power across the beams in Figure 7. For the post-sunset RTW signals the peak signals initially propagated on the north-west to south-east direction at local sunset. The preferred path then gradually moved around in an anti-clockwise direction until the optimum propagation direction was almost west to east around local midnight. Due to the low power of the daylight RTW signals it is difficult to assign an optimum propagation direction for this period.

Figures 8 and 9 show the minimum and maximum frequencies that supported RTW propagation, also for December 1993. For the post-sunset RTW signals the minimum frequency was approximately 10 MHz at sunset. The minimum frequency then increased up to a peak of 21 MHz by midnight. The upper frequency limit remained approximately constant through the night with a median value on the beam of optimum propagation of 23 MHz.

The frequency limits of the daytime signals were less varied on a day-to-day basis than the peak clutter powers discussed above. The lower frequency limit did not show the same strong increase over the course of the day that was observed for the post-sunset echoes. The lower frequency remained constant between 0930 LT and 1530 LT at approximately 16 MHz. The upper frequency limit also did not show any significant variation, remaining constant at 22 MHz.

3.1.2 Winter RTW Propagation

The occurrence of winter round-the-world echoes is in complete contrast to that seen during summer. Figure 10 illustrates the maximum clutter power for June 1993 in the same format as Figure 7. In winter there was only one period of RTW propagation observed during each day and it was exclusively a daytime phenomena. Every round-the-world ionogram recorded between the hours of 0730 to 1530 local time in June showed strong round-the-world echoes. Reception of the RTW signal commenced at sunrise with the signal strength increasing over the next few hours until it peaked just before noon. The signal then faded gradually until it disappeared just prior to local sunset.

The lower frequency limit, Figure 11, of the winter RTW propagation is similar in behaviour to that of the post-sunset summer echoes. It started at 10 MHz at dawn and slowly increases over the propagation period. The highest value of 17 MHz is reached near sunset. The upper frequency limit, Figure 12, increased quickly from 12 MHz at sunrise to 25 MHz three hours later. At noon it reached a peak of 26 MHz which coincided with the maximum signal strength observed during the day. The upper frequency then slowly decreased over the course of the next six hours to be 22 MHz at sunset.

3.2 Seasonal Variation in RTW Propagation

As discussed in the previous section there are significant differences in the propagation characteristics of round-the-world signals between summer and winter. In order to study the changes that occur over the course of the year between the two seasonal extremes, the median measurements for each month of the year were combined.

3.2.1 Occurrence of Day time and Post-sunset RTW

The variation in the monthly median of the maximum clutter power for 1993 is shown in Figure 13. There is one column on the x-axis for each month. The maximum clutter power found for each of the 8 beams at 1 hour resolution is plotted within the column for each month. The y-axis is time of day, the left-hand side is Universal time and the right-

hand side is local Alice Springs time. Blank areas on the plot result when insufficient measurements were made during the month to allow an estimate of the median for the hour. The times of local sunset and sunrise at the receiver site are also marked on the figure.

The two types of RTW propagation that were identified in the previous section, day time and post-sunset, can be seen in Figure 13. The first type, day time signals, were strongest during the winter months, May to August, but occurred throughout the year. They were observed at some azimuth in every month during 1993 during the mid-morning to mid-afternoon period. In contrast the post-sunset RTW echoes were only detected in the summer months, October to March.

The day time RTW echoes were detected from local sunrise to sunset, a period of at least 10 hours each day, for the nine months from February to October. By November the signal was difficult to detect above the noise level on most beams after mid-afternoon. The signals seen at 1730 LT, just before sunset, in November are early occurrences of the post-sunset echoes.

The second type of round-the-world propagation always commenced at or just before the time of sunset at Alice Springs. Post-sunset signals were then detected for a maximum of 8 hours a night in November and December. In March and October the echoes were only detectable for 2-3 hours commencing at sunset. Overall in 1993, the post-sunset type of RTW propagation occurred less often than the day time signals.

3.2.2 Variations in Maximum Clutter Power

The clutter level of round-the-world signals varied across the year, Figure 13, as conditions for the propagation of each type became more or less favourable. The maximum clutter power of the day time RTW signals peaked in June 1993 at -120 dBW. It decreased during the spring and autumn periods and by summer, November to January, the signals were 25 to 30 dB less than those measured during winter. The time of day when the largest day-time RTW signals were recorded remained constant from April to September at 0830-0930 LT. It was only in February, October and November that the time of peak day time power changed to 0630 LT.

The most intense post-sunset signals were recorded in December 1993, peaking at -128 dBW. Two months earlier, in October, the strongest post-sunset RTW echoes were 10 dB lower at -138 dBW. The time of occurrence of the maximum clutter remained the same, 1930 LT, over the period when post-sunset signals were detected. There may have been some variation in the time of maximum clutter across the months. However, the interval between ionograms, 1 hour, did not allow it to be measured.

3.2.3 Lower and Upper Frequency Limits

The median statistic for 1993 of the lower frequency limit of round-the-world propagation is shown in Figure 14. It shows the same lower frequency behaviour over the course of the day for both the day time and post-sunset cases. During the months of optimum propagation for both types, June and December, the minimum frequency of RTW signals started at 9-10 MHz just after propagation commenced. It then increased until it reached 16 MHz at the end of the RTW period. The rate of change of the lower frequency limit was greater for the post-sunset type causing the period of propagation to be significantly shorter.

However there was an asymmetry between lower frequency limits for the autumn and spring equinox periods. In autumn, March and April, the lower frequency commenced at 12 MHz at 2200 UT (0730 LT) and increased to a peak of 18 MHz at 0300 UT (1230 LT). It then remained approximately constant until 0700 UT (1630 LT). However in spring, September and October, the lower frequency limit commenced at 10 MHz and only reached a peak of 16 MHz over the same period. Thus the lower frequency limit was, in general, 2 MHz higher in autumn than it was in spring at the same time of day.

The upper frequency limit for 1993, Figure 15, remained approximately constant over the propagation period after an initial increase for both day time and post-sunset RTW signals. In June the day time signals started propagating with an upper limit of 13 MHz at sunrise (0630 LT). The frequency limit rapidly increased to 27 MHz by 0930 LT and then remained constant until sunset. The maximum frequency limit of the post-sunset signals in December started at 17 MHz at 1830 LT. Within an hour it had increased to 24 MHz then it did not change significantly for the rest of the RTW period.

The upper frequency limit also shows a similar asymmetry between the equinoxes to that seen in the lower frequency limit. Again the frequencies in March and April were significantly higher than those in September and October. On average the autumn upper frequencies were 4 MHz higher than those at the equivalent times in spring. A peak of 28 MHz was reached in April as opposed to a maximum of 23 MHz in September, both at 1330 LT.

3.2.4 Frequency of Maximum Signal Power

The frequency at which the maximum RTW clutter power was recorded varied during each 24 hour period as conditions for propagation altered. In general the maximum signal strength occurred at a frequency within 10% of the midway point between the lower and upper frequency limits. A plot for 1993 of the frequency of maximum clutter power (corresponding to the maximum RTW power of Figure 13) is shown in Figure 16.

For both day time and post-sunset types of RTW signal propagation commenced with the maximum clutter frequency at 11-12 MHz. Over the course of the propagation period the frequency increased to a peak of 21 MHz. The peak frequency was recorded near the end of the propagation period for both types of RTW signal. The peak for the day time echoes in June occurred at 0600 UT while for the post-sunset signals it occurred at 1500 UT. The frequency at which maximum clutter was recorded remained 4-5 MHz above the lower frequency limit for RTW propagation over the entire year.

As previously seen in the plots of the lower and upper frequency limits, propagation during the autumn equinox exhibited different behaviour to that of spring. In April 1993 the maximum clutter was recorded at a frequency of 23 MHz during the afternoon while in September it was lower, at 19 MHz, again during the afternoon. The differences were smaller, 2 MHz, when the RTW signals commenced propagating after sunrise but they increased until mid-morning when a constant 4-5 MHz differential was established.

3.2.5 Summary of Seasonal Variation

The conditions required for propagation of round-the-world signals during the daylight hours are regularly established throughout most of the year. Day time RTW signals are strongest in winter and decline in power through spring. They reach a minimum in summer that is 25 to 30 dB less than the winter peak then gradually increase again through autumn. The signals are detectable for at least 10 hours during each day for approximately 6 months commencing in April. It is only at the peak of summer that they are observed for less than 6 hours during the daylight hours.

In contrast to this post-sunset RTW propagation is only supported during the summer months. They are first visible in October for 2 hours after sunset. The post-sunset signals peak in December/January and are last detected in March. At the peak time for the reception of the post-sunset signal in 1993, the clutter levels recorded were almost the same as those at the peak of the day time signal in winter. They both reached a maximum level of -125 dBW on the beam of optimum propagation, the post-sunset type at 1000 UT (1930 LT) in December and the other in June at 0000 UT (0930 LT).

The lower and upper frequency limits for both types of RTW signals show similar features. It is only during the autumn equinox period that a significant difference is apparent in the frequency behaviour of the day time round-the-world propagation. Here the frequencies (lower and upper frequency limits as well as frequency of maximum clutter power) occupied by the RTW signal are 3 to 4 MHz higher than at any other time. In contrast the spring equinox period has frequencies that are following the trend from higher in winter to lower in summer.

3.3 Evidence of Solar-Cycle Effects

The ionosphere is strongly influenced by long term changes in the output of solar radiation as measured by the sunspot index and the output of 10cm radio waves. These changes manifest themselves as variations in HF propagation conditions, for example frequency limits and signal strengths. It should be expected then that solar-cycle variations should be detectable in the behaviour of round-the-world signals. The sunspot number for the period from 1987 to 1994, Figure 17, shows a rapid increase from low levels in 1987 to a broad peak between 1989 and 1991 and then a gradual decline to a minimum in 1994. The largest effects might be expected to be seen between years of peak solar activity like 1989 and those of low levels such as 1994. Unfortunately the RTW data from Alice Springs does not include a high sunspot year. The average sunspot numbers for the years that RTW data has been collected at Alice Springs are 29.2 for 1987, 54.6 for 1993 and 30.8 for 1994. Both 1987 and 1994 could be generally described as low sunspot years while 1993 is medium-low.

3.3.1 Maximum Clutter Power

Plots of the maximum clutter power parameter for 1987 and 1994, Figures 18 and 19, shows similar features as that for 1993, Figure 13. Again the day time type of propagation was strongest and was observed for longer during each day in winter, gradually decaying towards summer. The post-sunset RTW signals were only seen during the summer months and were as intense at their peak as the day time signals. In general, the clutter powers recorded for spring-summer 1987 were as strong or stronger to those for the same period in 1993. The cause is likely to be the level of solar activity through late 1987 reaching levels equal to or above those of spring-summer 1993. Note that a number of system changes to the backscatter sounder between 1987 and 1993 have resulted in an improvement of the system sensitivity. This upgrade has resulted in the backscatter sounder being able to better detect lower level RTW signals.

Comparison of the maximum clutter power for 1993 to that for 1994 shows significant differences. The overall level of clutter power is reduced in 1994 by 3 to 5 dB for most hours in the corresponding months. For example in June 1993 at 0200 UT the maximum clutter power was -130 dBW recorded on beam 5. In June 1994 at the same time the maximum clutter power was -136 dBW on beam 5. Due to the decrease in power received the range of azimuths that the RTW signal was seen on has reduced. The round-the-world echoes were recorded on all beams between 08:00 and 16:00 LT during May to July 1993. In 1994 the echoes were not detectable above the noise level on some beams during the same period.

3.3.2 Frequency Related Parameters

The lower frequency limit for 1994, Figure 20, shows little change from that of 1993, Figure 14. One of the primary differences is that during winter 1994 the day time propagation commenced 1 MHz lower than seen in 1993. The region of increased lower frequency limit seen during the autumn equinox of 1993 is not as prominent in 1994.

However the upper frequency limit for 1994, Figure 21, shows greater change from that of 1993. The 1994 winter day time signal has a peak frequency that is suppressed by 3 to 4 MHz over most of the day compared to 1993. The change in the upper frequency limit for the post-sunset type is less between the two years, being about 1 MHz. As for the lower frequency limit, the increase in the upper frequency limit for the day time signal during autumn is not as large as seen in 1993 but it is still apparent.

The frequency of maximum clutter power for 1994, Figure 22, also shows an overall reduction in frequency when compared to 1993, Figure 16. The largest frequency differences are 3 Mhz that occur for the day time echoes during winter. The post-sunset echoes seen during summer are not suppressed by quite as much, suffering a reduction of only 1 to 2 Mhz.

3.3.3 Area of RTW Trace

The parameter that shows the largest differences between the RTW traces for 1993 and 1994 is the area occupied by the echo. The area of each RTW ionogram is calculated by totalling the number of delay-frequency cells between 135 and 145 milliseconds that contain echo power above the background noise. Thus this parameter would be expected to be sensitive to not only changes in span of frequencies that are propagating but also the width of the RTW trace. The width of the trace can be affected by two things, the number of "modes" visible and the power of the signal. The round-the-world ionogram shown in Figure 3 has two "modes" visible at 15 MHz but only one "mode" can be seen at higher frequencies. Often only a single "mode" is recorded. The effect of increasing the signal strength of the RTW echo is to increase the signal to noise ratio of the outer areas of the trace and thus increase the area.

The values recorded for the area of the round-the-world trace for 1993 and 1994 are shown in Figures 23 and 24 respectively. The day time echoes show decreases in area of 44% from values of 270 cells in June 1993 at 0000 UT to 150 cells in June 1994. The difference in September at the same time of day for both years is similar showing a decrease of 38%. The post-sunset signals also show a significant decrease in area in 1994 compared to 1993. The magnitude of the decrease is more variable than that seen for the day time echoes, but is generally smaller at around 20%. The smoothed sunspot numbers for corresponding months in 1993 and 1994 (e.g. June 1993 compared to June 1994) show an approximately constant decrease of about 50% for the months from January to July. From August to December the decrease gradually becomes less, changing from 43% in August to 14% by December. This corresponds closely with the changes in round-the-world trace area over the same period.

3.4 Optimum Direction of RTW Propagation

One of the striking features of the figures presented which show azimuth (beam direction) as a function of time of day is that the preferred direction for round-the-world propagation changes through the day in a consistent fashion. For example the plot of maximum RTW clutter power for 1993, Figure 13, shows that the beam on which the maximum clutter power is recorded changes during the day. For the day time signal in June the peak clutter signal was first recorded on beam 3 (330° Tx, 150° Rx) at 2200 UT (0730 LT). It then moved anti-clockwise through the day reaching beam 7 (285° Tx, 105° Rx) at 0400 UT (1330 LT). The post-sunset signal in December 1993 peaked on beam 3 at 1000 UT (1930 LT). It also rotated anti-clockwise over the next few hours finishing on beam 7 at 1400 UT (2330 LT).

Fenwick [1963] has studied this behaviour in detail and has produced a simple theory that can be used to predict the direction of optimum RTW propagation. In this simple theory the only factor that affects the RTW signal is the attenuation in the ionosphere, primarily due to solar radiation. Thus the optimum direction of propagation is defined to be the one that provides a path around the earth that maximises the distance from the sub-solar point. From this point of view the best path would be the one that travels along the band of twilight between the day light and dark hemispheres. Because all of the RTW signals are assumed to travel on great circles this path is, of course, only available when the transmit/receive site also lies in the twilight zone.

Fenwick's formulation of the optimum propagation direction is given as

$$A = 90° - \cot^{-1}\left(\frac{\tan\delta\cos\phi}{\sin h} - \sin\phi\cot h\right) \qquad 2$$

where A is the optimum azimuth

δ is the declination of the sun

ϕ is the latitude of the transmit/receive site

h is the sun's hour angle relative to the transmit /receive site

This gives the direction normal to azimuth of the sub-solar point as seen from a given transmit/receive site.

Figure 25 shows the optimum direction of RTW propagation for Alice Springs as measured with the backscatter sounder against the theoretical azimuth from Equation 1. It shows the data for the winter months (May to August) for 1987, 1993 and 1994. Note that the only winter month with available RTW data in 1987 was August. Theoretical curves

for winter (solar declination of 23.4°) and the equinox (solar declination of 0°) are plotted as a function of hour of the day. The measured values of the optimum azimuth were determined from the monthly median values of maximum clutter power as shown in Figure 13 for 1993. For each hour in the given month a curve was fitted to the 8 beam values and the azimuth that gave the maximum clutter value interpolated. This azimuth was then plotted on the figure at the appropriate hour. Also plotted on the graph are lines indicating the extent of the azimuth field of view of the FMS receiver array.

We can see that for the period from 0730 LT (2200 UT) to 1030 LT (0100 UT) the measured values of optimum azimuth lie closely bunched around the theoretical winter curve as expected. Also the theoretical curves remain inside the field of view of the receiver beams. The anti-clockwise rotation of the optimum azimuth can be seen. However from 1130 LT (0200 UT) until the propagation ceases at 1730 LT (0800 UT) the points become more scattered and do not lie close to the theoretical curves. This is due to the optimum propagation azimuth moving outside of the field of view of the receiving system. Thus any RTW signals received will be via the sidelobes of the receiving beams and not the main lobes. The intensity of the sidelobe signals as a function of direction is difficult to accurately model for the FMS antenna array. Thus it is difficult to determine which direction the real signals are coming from when only the sidelobes are visible.

The corresponding plot for the summer months (November to January) of 1987 to 1994 is shown in Figure 26. Again it shows a close grouping of the measured optimum azimuths with the theoretical curve for the period when the predicted azimuth fell within the FMS beam limits. This was the period from 1830 LT (0900 UT) to 2330 LT (1400 UT). Outside these times the post-sunset RTW signal had generally ceased propagating however the weak day time echoes were visible. They showed a large scatter in optimum direction that is similar to that seen on the afternoon echoes recorded in winter.

Fenwick [1963] has also developed more sophisticated models for the optimum propagation direction that take into account the effects of variations in the F2 ionospheric layer. These involve using global maps of f_0F2 (the critical frequency of the ordinary ray in the F2 layer) to select the path that has the highest average f_0F2 as the optimum azimuth. From the data that has been examined here it does not appear to be necessary to invoke such sophisticated models. The measured data fits the simple model well in the regions when the optimum azimuth lies within the beam limits for both day time and post-sunset echoes.

4. Conclusions

4.1 Temporal and Seasonal Variation

The results presented in this report show the temporal and seasonal variation in the occurrence of round-the-world HF signals. In general RTW signals can be detected strongly during daylight hours in winter and for some period after sunset in summer. This confirms the previous studies in this area by workers such as Quack and Mogel [1929], Hess [1948] and Fenwick [1963].

A point not noted by previous authors is that RTW propagation can also be detected during the day in summer. Examining the behaviour of the frequency of maximum power for both the daytime and post-sunset RTW signals confirms that they are two separate classes of echoes. In summer the day time section of propagation follows the pattern of that in the winter months for the same times of day. However there is no equivalent propagation in winter for that seen in summer, post-sunset. This leads to the view that there are two distinct types of RTW signals, daytime and post-sunset. The daytime signals are seen through most of the year and are strongest in the winter months. The post-sunset signals are strongest in the summer half of the year and not observed at all in winter.

Another area where the results presented here significantly improve on previous work is the wide coverage in both time and frequency of the RTW measurements. Earlier authors who have presented statistics on the occurrence of RTW signals have often used fixed frequency systems that have only been able to monitor a very limited number of frequencies. The use of the FMCW backscatter sounder has enabled the entire 5 - 45 MHz band to be covered with each sounding. Thus the maximum RTW clutter power over the HF band and the frequency at which it is received can be scaled from each ionogram. The data presented also covers a larger time span (nearly two and a half years) than any published by previous workers.

The peak power of the RTW ionograms reached -120 dBW in winter 1993 and -128 dBW in summer 1993. The frequency of maximum RTW power data shows that the optimum frequency for propagation remains 4 to 5 MHz above the lower frequency limit at any given time. It varies from 11 to 21 MHz over the course of the year. This band of frequencies is also one of the most useful for OTH radar operations so it is important to determine what impact this will have on target detection capability. To do this requires an estimate of the Doppler characteristics of the RTW signal which has not yet been systematically studied.

4.2 Seasonal Asymmetry in RTW Signals

An interesting feature, not noted by other authors, is the asymmetry in the frequency characteristics of the RTW signals between the spring and autumn equinoxes. The data shows the frequencies, both the upper and lower frequency extremes as well as the frequency of maximum clutter power, are 3 to 5 MHz higher in autumn than for the spring period. However the maximum clutter power recorded does not differ significantly between the autumn and spring equinoxes. An explanation for this behaviour can be found in the ionospheric maps of f_0F2 for the afternoon hours in the Alice Springs region which show similar structures during each of the equinoxes. However the autumn equinox has vertical critical frequencies that are approximately 1 MHz higher than the spring equinox. Due to the RTW signals propagating using very low angle rays this frequency difference is exacerbated and could thus explain the observed 3-5 MHz difference.

4.3 Solar Cycle Variation in RTW Signals

The data shows clear solar cycle variations in both the signal strength and frequency characteristics of the RTW echoes. The sunspot number declined from an average of 54.6 in 1993 to 30.8 in 1994. The maximum signal power was 3 to 5 dB higher overall in 1993 compared with 1994. It is likely that the maximum power would be even greater at sunspot maximum, however further measurements are needed to confirm this. The frequency characteristics of the RTW signals also show the influence of the solar cycle variation. The upper frequency limit of the winter day time echoes showed the greatest change. In 1994 they were suppressed by 3 to 4 MHz compared with the same period in 1993. In general both the signal power and frequency extents of the RTW signals decreased with decreasing sunspot number over the period of observation.

4.4 Optimum Propagation Direction

The direction of optimum propagation is shown to be accurately predicted by Fenwick's simple model when the signals lie within the main coverage of the FMS receiver array. It is only when the optimum azimuth lies outside this region that the data becomes scattered. The scatter in the points is due to the signal being received via sidelobes of the array rather than a main beam. It may be possible to use this data, assuming it will continue to follow the predicted azimuth, to map out the sidelobes of the FMS array. However this work is beyond the scope of the current report. In any case the simple model should be sufficient to allow radar operators to predict the optimum azimuths for much of the period when RTW propagation is detectable. It is only for the period from 1300 to 1800 LT in winter and during the low power day time signals in summer are present that the simple model would not predict the observed optimum azimuth correctly.

5. Future Work

There is scope for continuing examination of round-the-world propagation to enable the solar cycle dependence of the phenomenon to be fully examined. This would require regular measurements of RTW signals through both the low and high parts of the solar cycle. These long term results should show which characteristics of the signals are affected by the bulk changes in the ionosphere. The use of the new orthogonal FMS receiving array which provides 360 degree coverage will also allow the RTW phenomena to be measured unambiguously beyond the present azimuth limits.

Measurements on the Doppler spread of the round-the-world signals are also required. These, combined with the occurrence and power statistics reported here, will enable an estimation of the impact of the RTW phenomena on radar operations. Then mitigation strategies can be determined to reduce the effect on radar target detection capabilities.

There has been a considerable body of work published on the prediction of round-the-world signals using a technique known as the adiabatic invariant (see Gurevich and Tsedilina [1985] or Tichovolsky [1984] for summaries of this work). This model uses ionospheric maps such as IRI or IONCAP to predict the extent of trapping of radio waves in ionospheric ducts. This allows the frequency extents of RTW signals to be found. However there are difficulties determining the absorption along the path. This means that it is difficult to model clutter powers and thus simulate RTW ionograms using this technique.

These problems could be overcome by the development of an accurate raytracing model. This would enable predictions of the received power and frequency limits of the RTW signals to be made. These predictions could then be used to warn the radar operators of frequencies that could be adversely affected by this phenomena. It could also lead to a better understanding of the mechanisms underlying the various round-the-world related phenomena.

6. References

1. Bubenik, D.M., A.C. Fraser-Smith, L.E. Sweeney, Jr. and O.G. Villard, Jr. (1971), "Observations of Fine Structure in High-Frequency Radio Signals Propagated Around the World", J. Geophys. Res., 76(4), 1088-1092

2. Earl, G.F. and B.D. Ward (1987), "The Frequency Management System of the Jindalee Over-the-Horizon Backscatter HF Radar", Radio Sci., 22(2), 275-291

3. Fenwick, R.B. (1963), "Round-the-World High-Frequency Propagation, Tech. Rep. 71, Stanford Electron. Lab., Stanford Univ., Stanford, Calif.

4. Fenwick, R.B. and O.G. Villard, Jr (1963a), "A Test of the Importance of Ionosphere-Ionosphere Reflections in Long Distance and Around-the-World High-Frequency Propagation", J. Geophys. Res., 68(20), 5659-5666

5. Fenwick, R.B. and O.G. Villard, Jr (1963b), "Measurements of the Frequency Dependence of Round-the-World, HF Pulse Time Delays and Dispersions", Proc. IEEE, 51(9), 1240-1241

6. Grossi, M.D. and B.M. Langworthy (1966), "Geometric optics investigation of HF and VHF Guided Propagation in the Ionospheric Whispering Gallery", Radio Sci., 1(8), 877-886

7. Gurevich, A.V. and E.E. Tsedilina (1985), "Long Distance Propagation of HF Radio Waves", Physics and Chemistry in Space Vol. 12, Springer-Verlag, Berlin

8. Hess, H.A. (1948), "Investigations of High-Frequency Echoes", Proc. IRE, 36, 981-992

9. Isted, G.A. (1958), "Round-the-World Echoes", Marconi Rev., 21(131), 173-183

10. Quack, E. (1927), "Propagation of Short Waves Around the Earth", Proc. IRE, 15, 341-345

11. Quack, E. and H. Mogel (1929), "Double and Multiple Signals with Short Waves", Proc. IRE, 17(5), 791-823

12. Tichovolsky, E.J. (1984), "HF Prediction Using Adiabatic Invariant Theory", RADC-TR-84-59, Rome Air Development Center, Griffiss Air Force Base, New York

THIS PAGE INTENTIONALLY BLANK

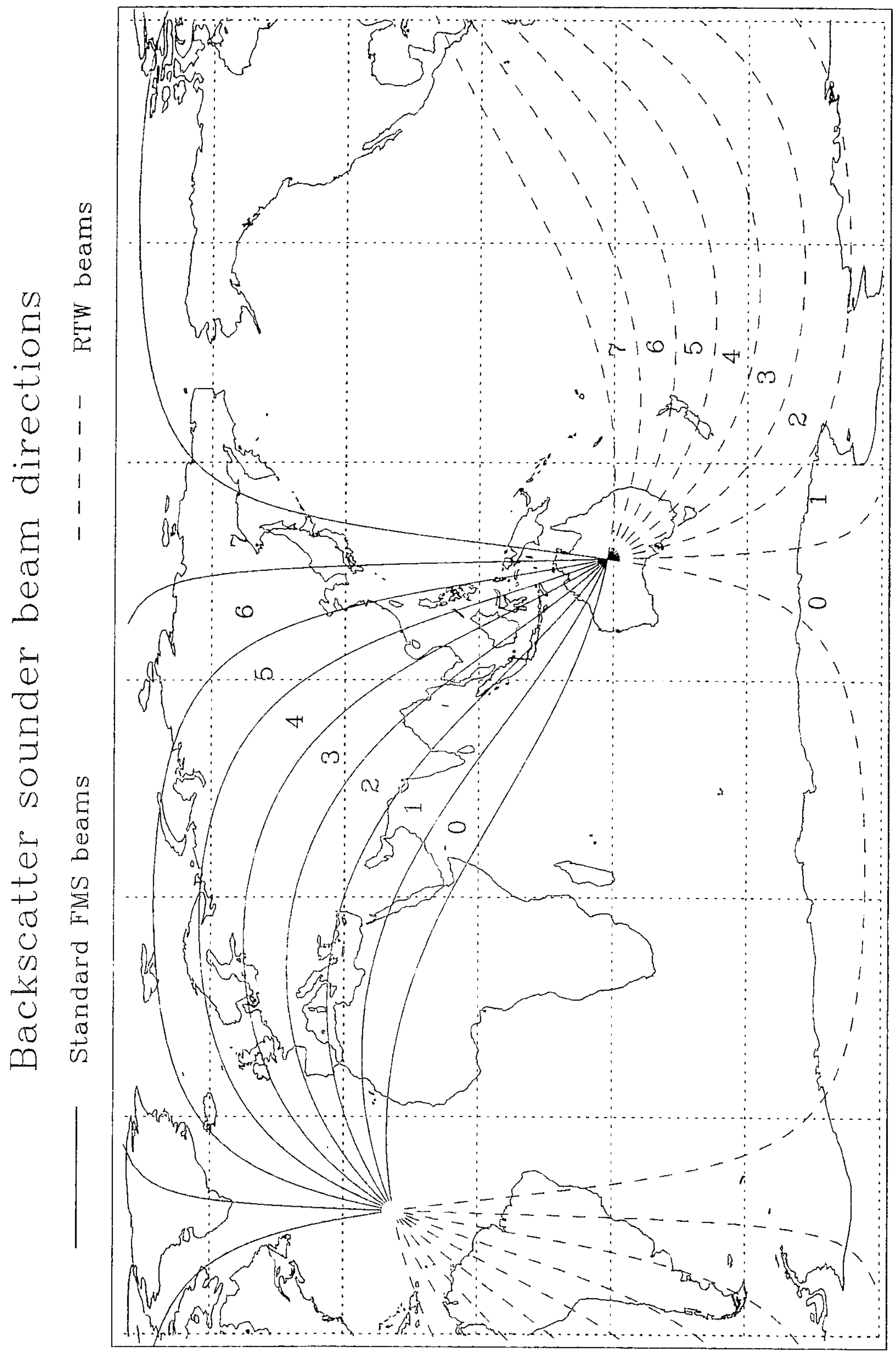


Figure 1: *The receiver beam directions for the FMS backscatter sounder (solid lines). Also shown are the round-the-world receiver beam directions (dashed lines).*

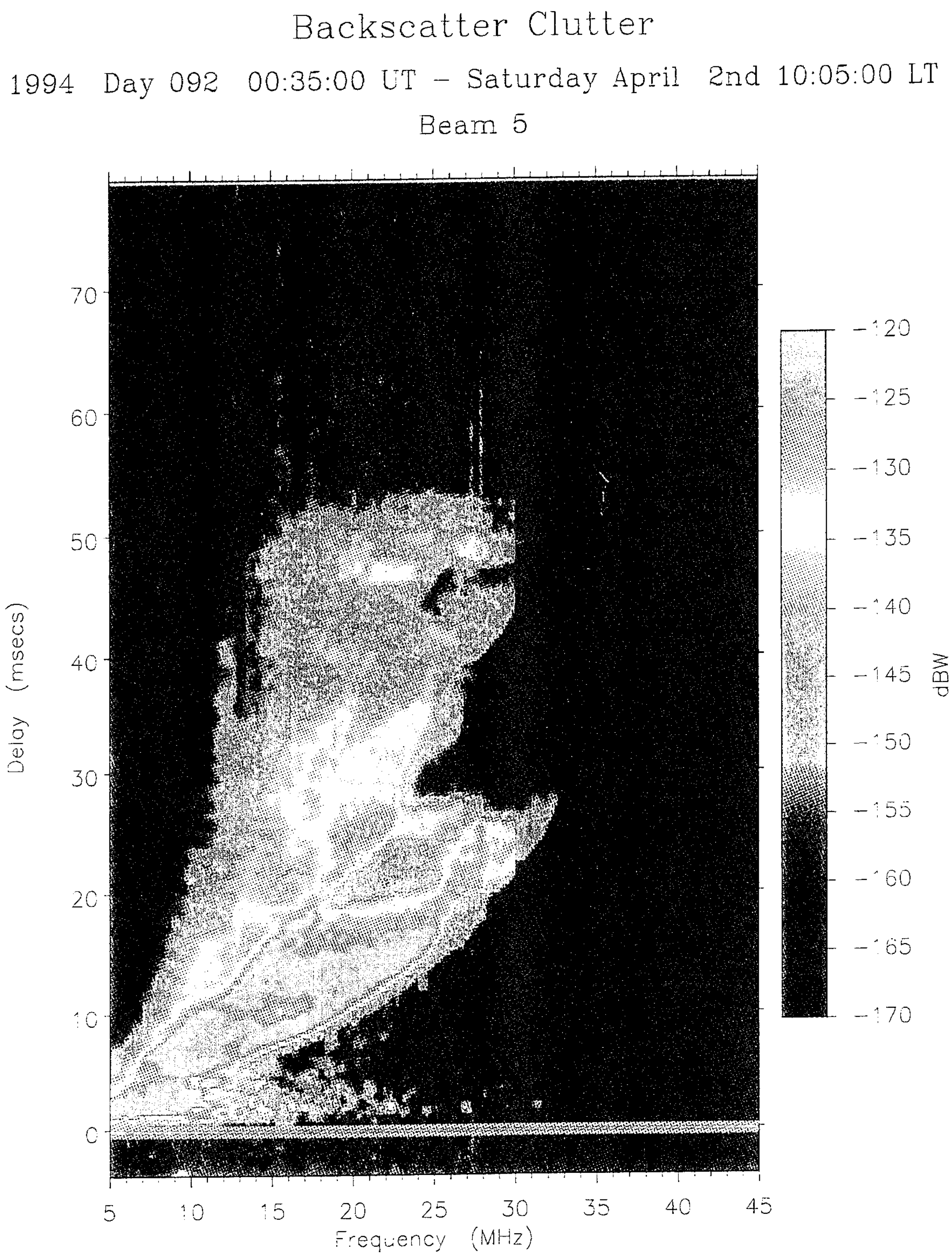


Figure 2: *An example of a backscatter ionogram recorded using the FMS backscatter sounder. The Ionogram was recorded on beam 5 at 00:35:00 UT on Sunday April 2nd 1994. Strong one and two-hop echoes can be seen between 5 and 30 Mhz.*

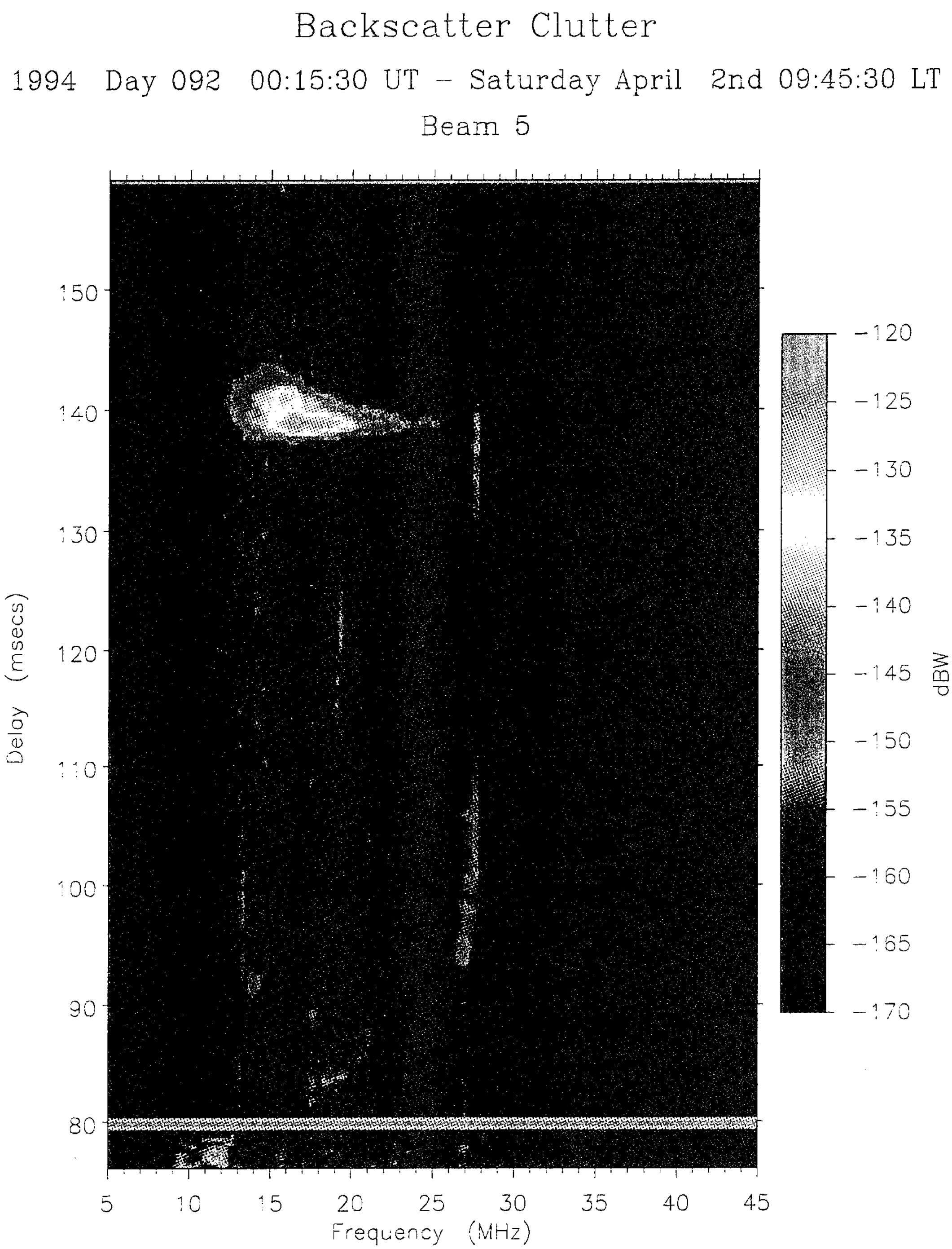


Figure 3: *The round-the-world ionogram recorded approximately 15 minutes before the backscatter ionogram shown in figure 2. The RTW signal was more confined in frequency and delay than the backscatter ionogram. Note the presence of a second "mode" located just beyond 140 Milliseconds delay.*

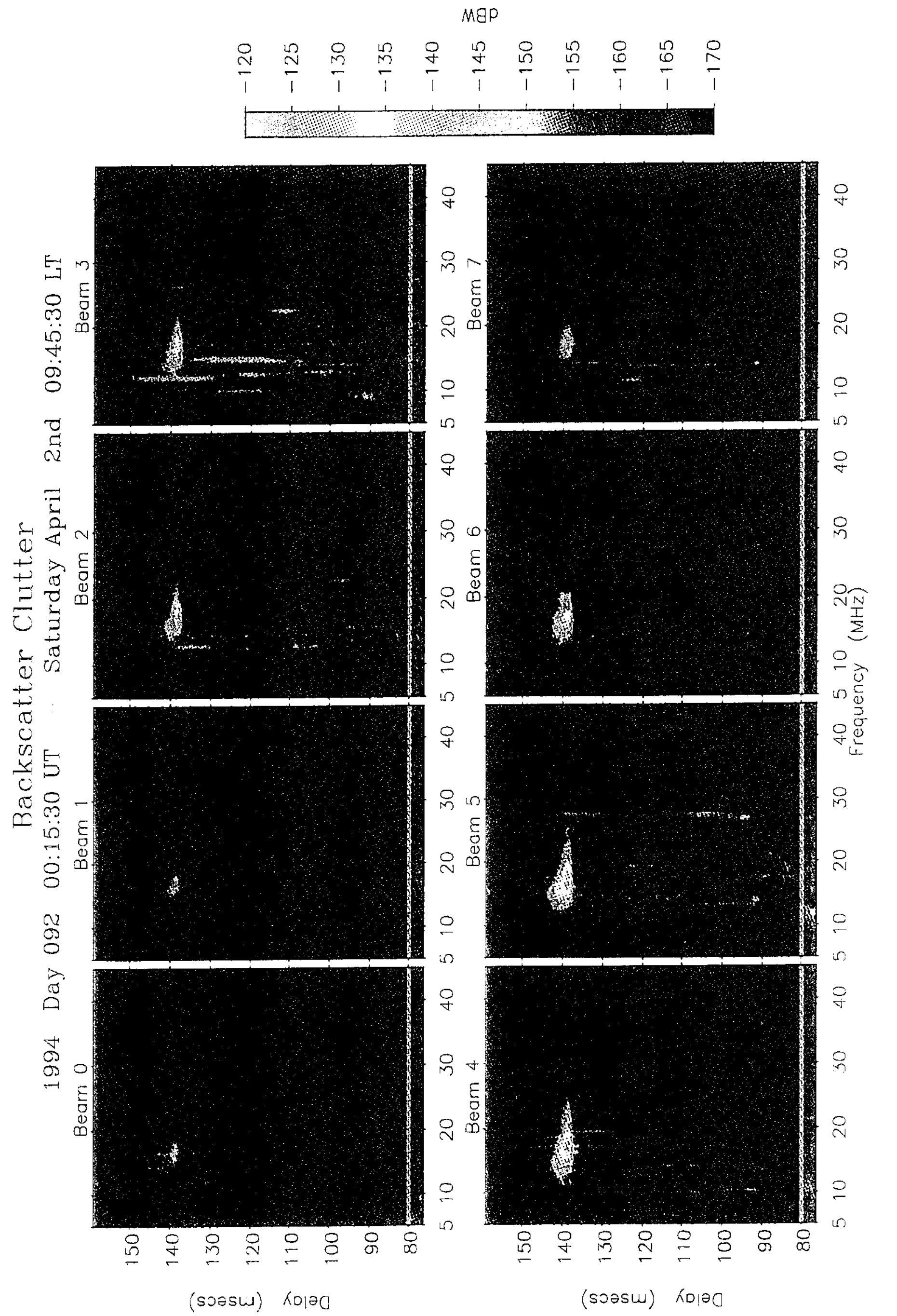


Figure 4: *The azimuthal variation in signal strength can be appreciated from the RTW ionograms recorded simultaneously on eight FMS beams. The strongest RTW signal was recorded on beam 5.*

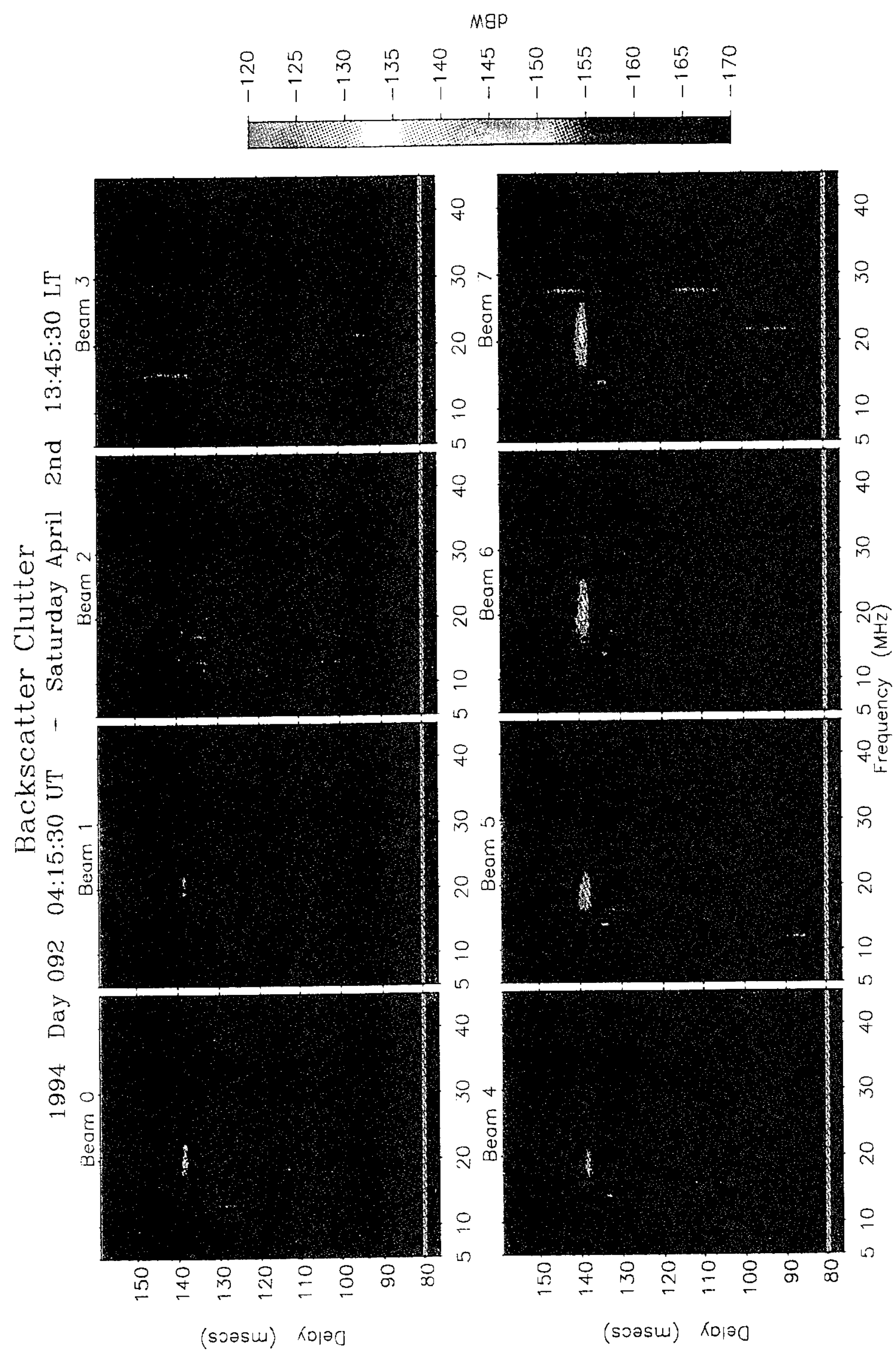


Figure 5: *A set of RTW ionograms recorded four hours after those shown in figure 4. The strongest signal is now on beam 7. The weak RTW signals seen in beams 0 and 1 are due to sidelobes of the receiver beams.*

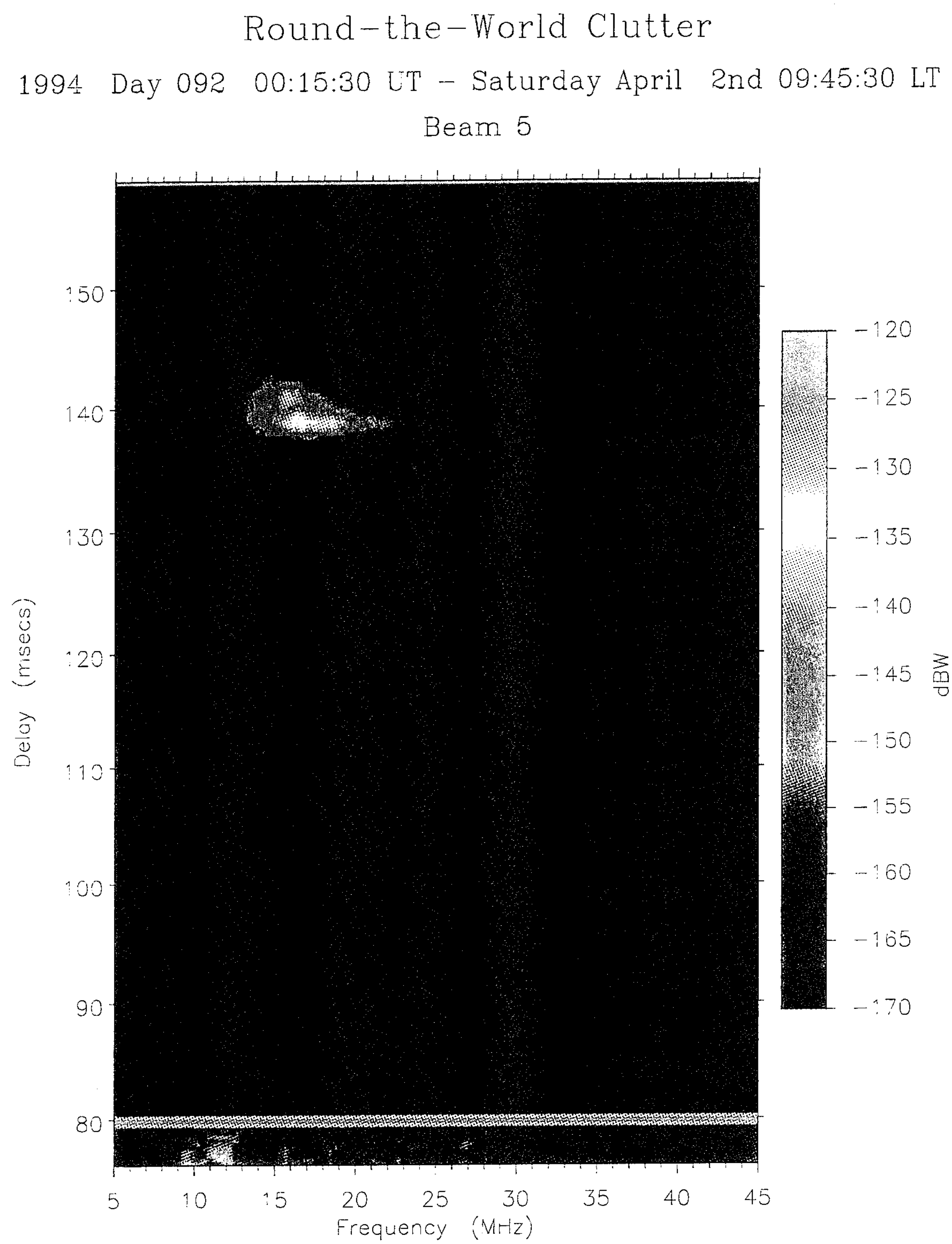


Figure 6: *The cleaned up RTW ionogram corresponding to the data shown in figure 3. The background noise field has been removed and the signal corrected to a constant 1 kW of transmitter power at all frequencies.*

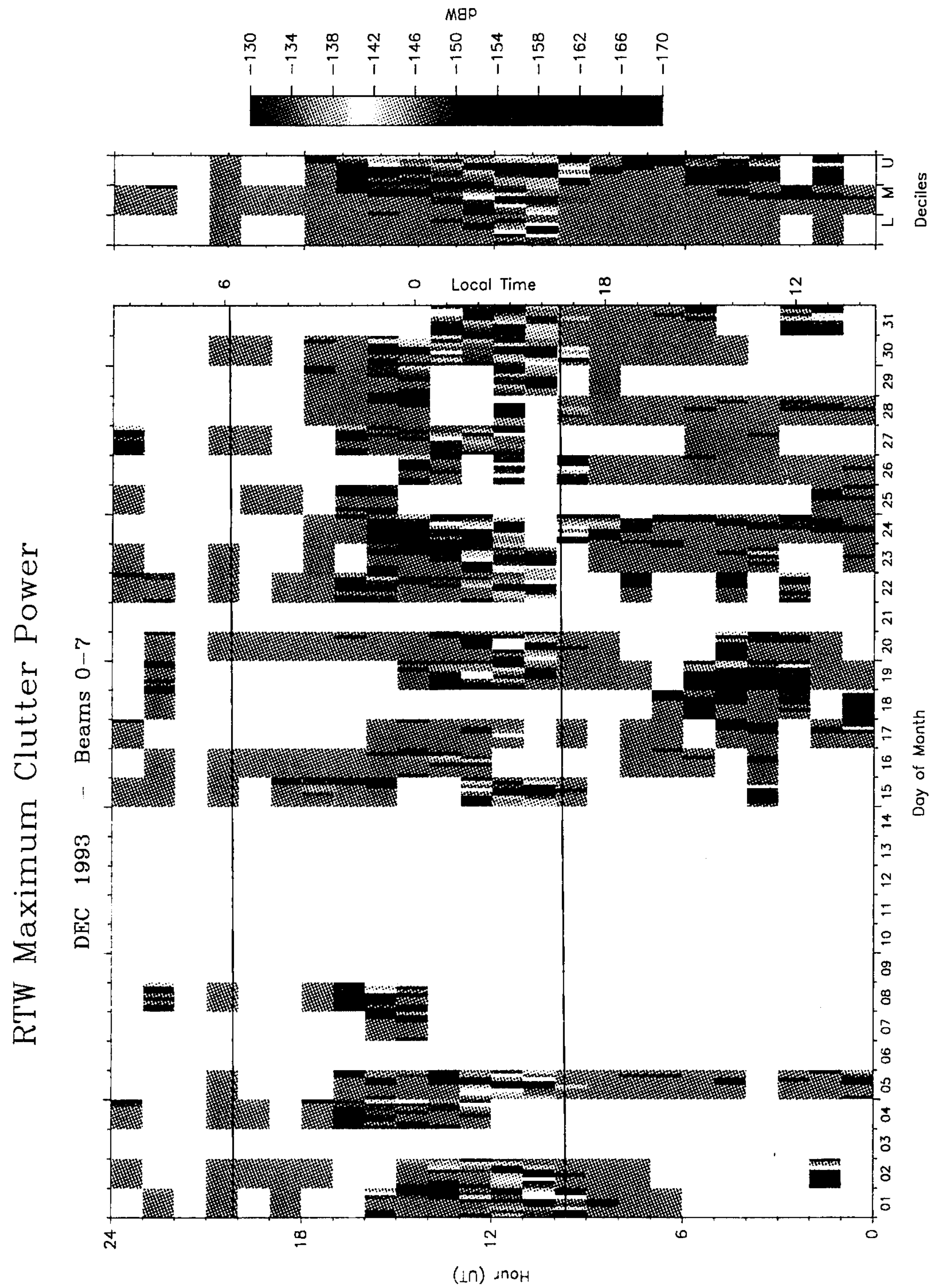


Figure 7: *The maximum clutter power recorded on each RTW ionogram measured during December 1993. Within each day column the values for the eight beams (0-7, left to right) are plotted. The times of sunset and sunrise at Alice Springs are marked. Note the weak day time and strong post-sunset signals. The smaller plot to the right shows the lower, median and upper decile levels for the month.*

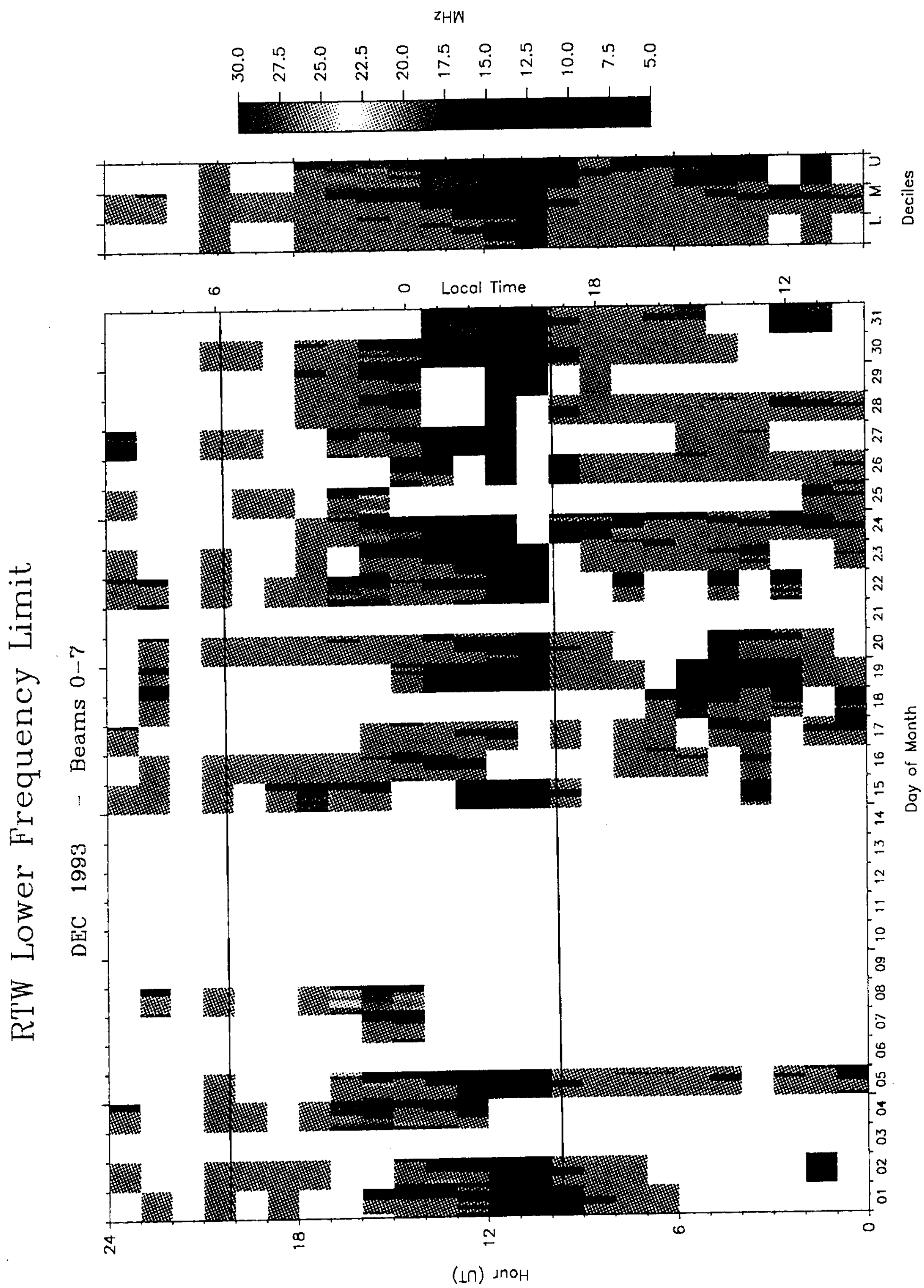


Figure 8: *The lower frequency limit of the RTW ionograms during December 1993. The format is the same as for figure 7.*

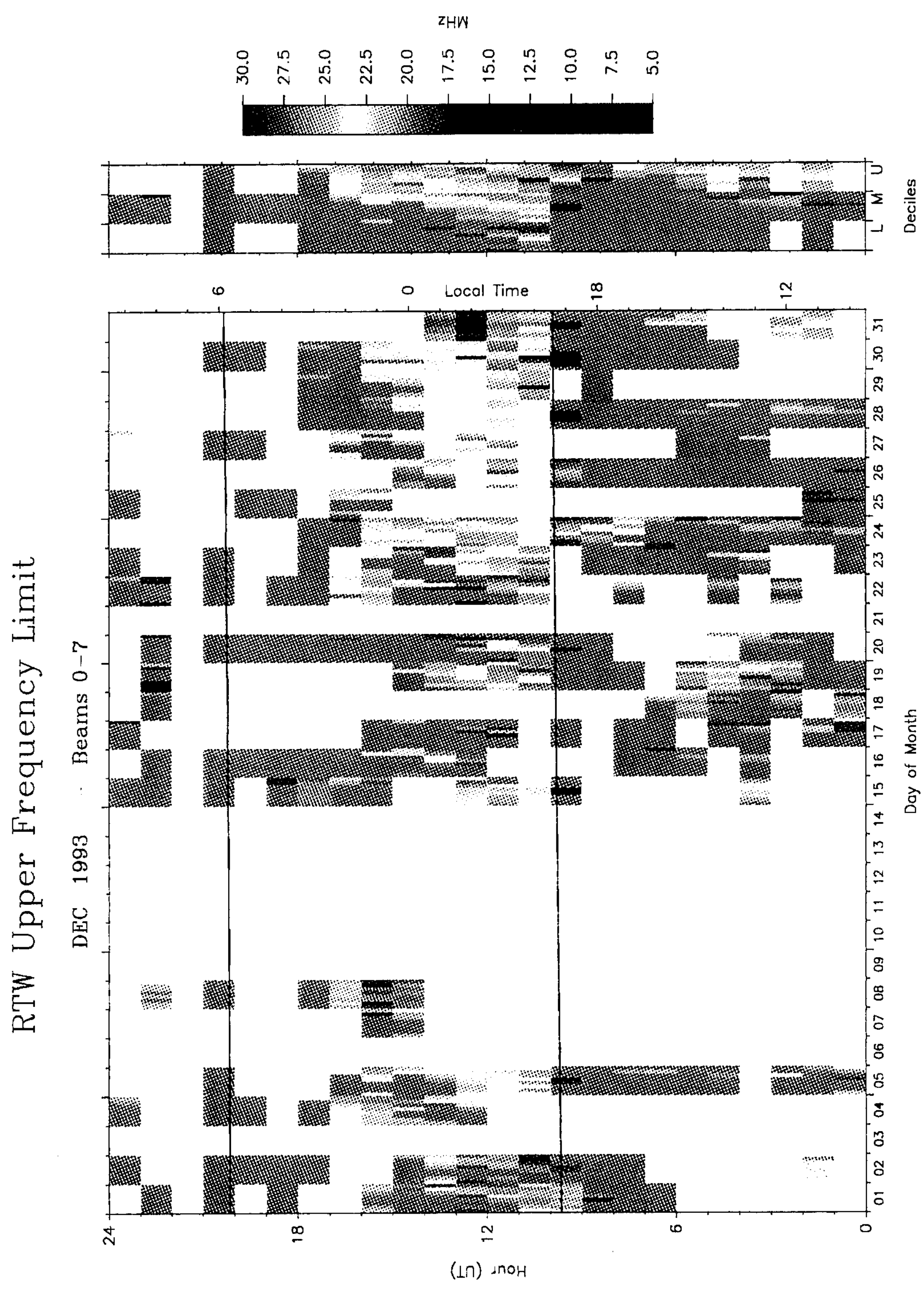


Figure 9: *The upper frequency limit of each of the RTW ionograms recorded during December 1993.*

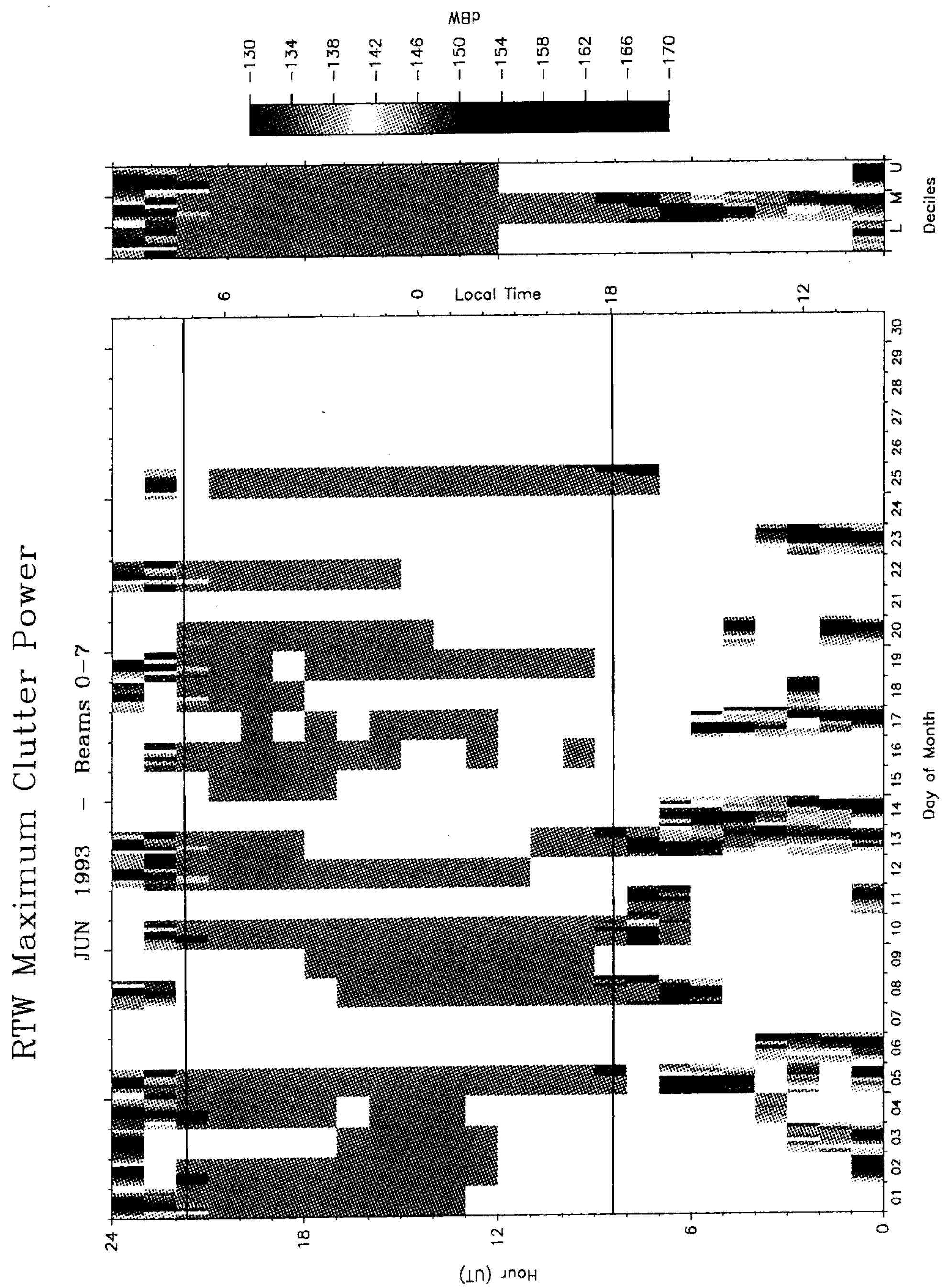


Figure 10: The maximum clutter power for June 1993 in the same format as figure 7. Strong RTW clutter returns were only recorded during the daylight hours.

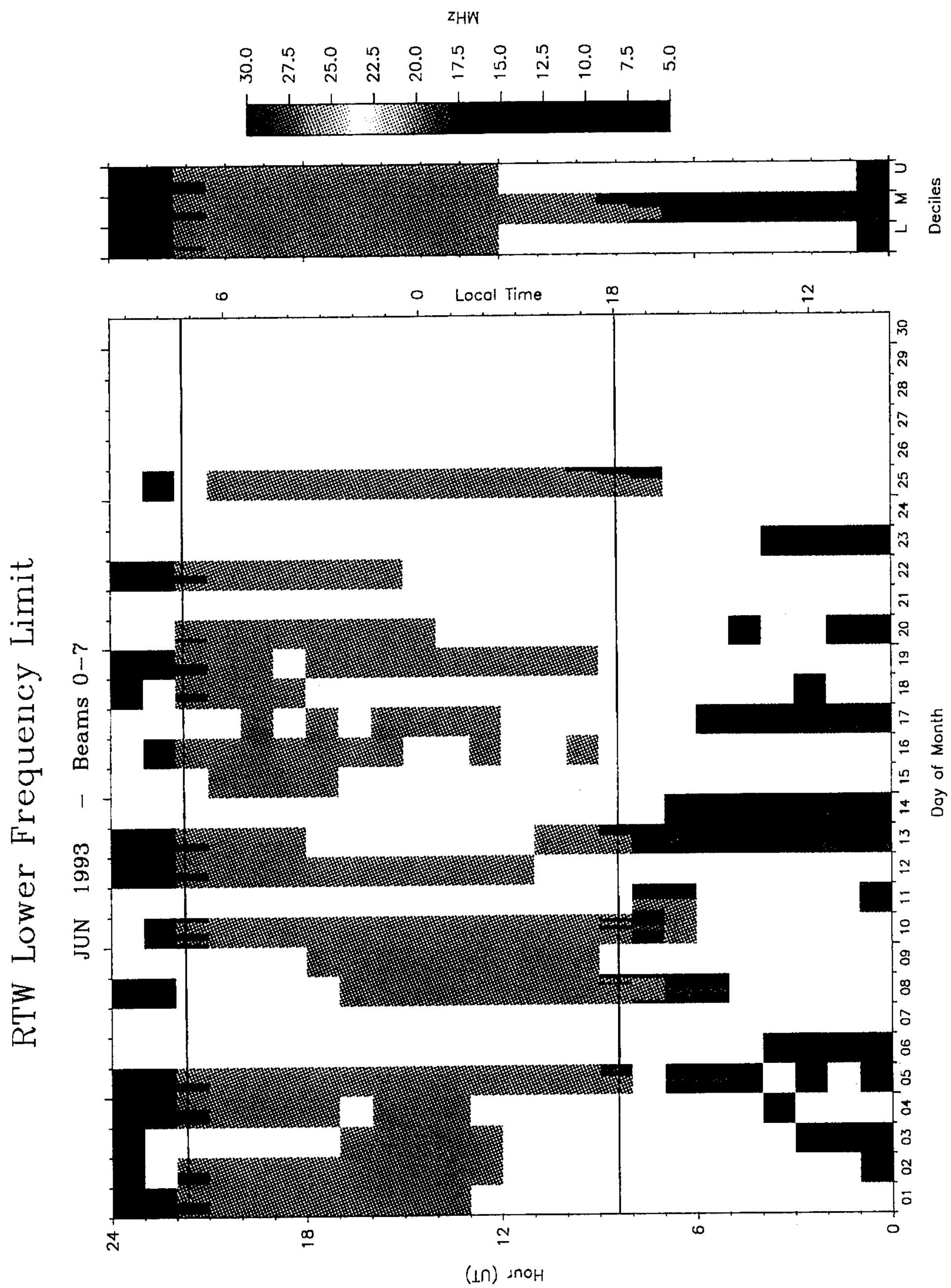


Figure 11: The lower frequency limit for June 1993.

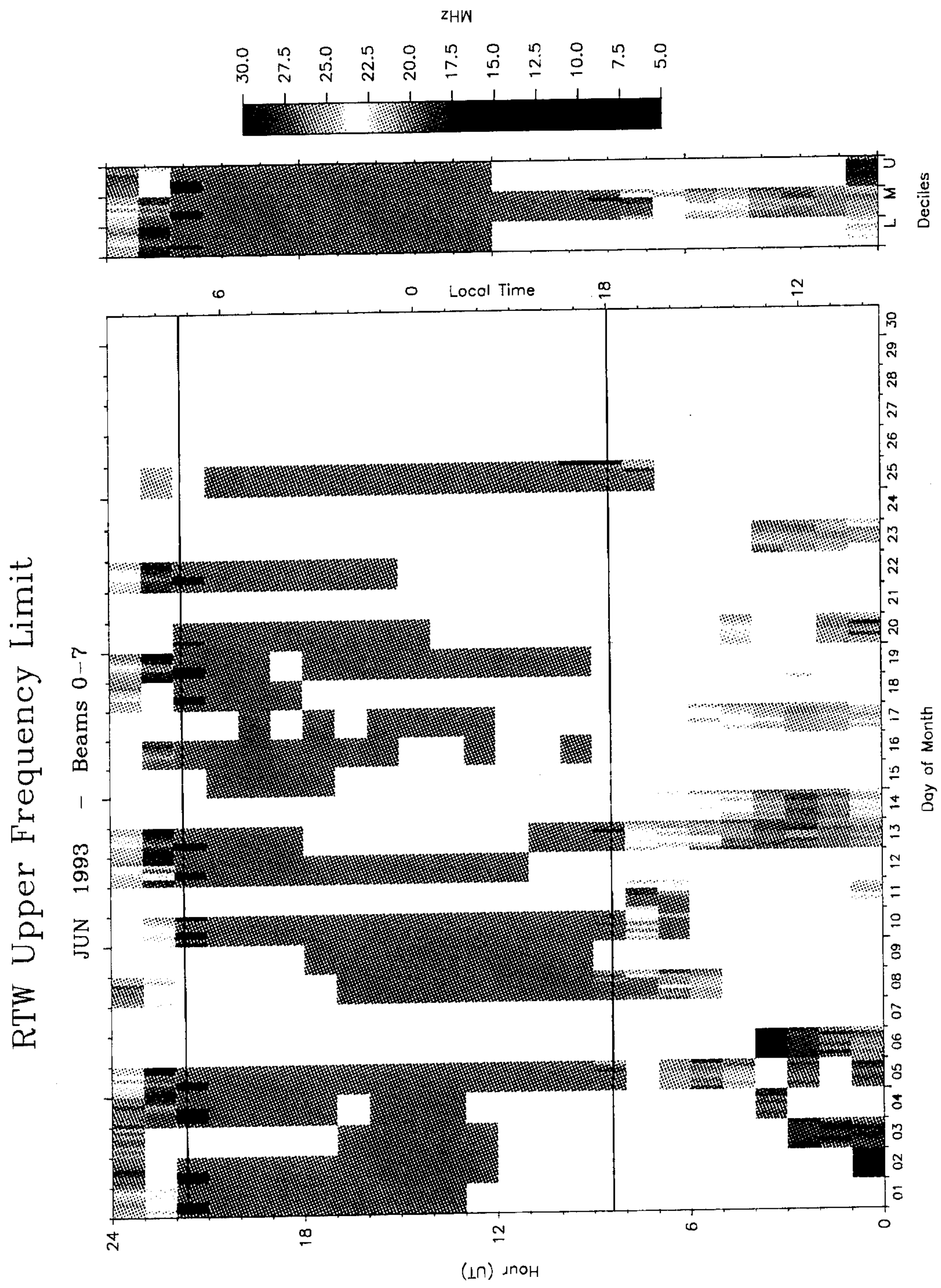


Figure 12: The upper frequency limit for June 1993.

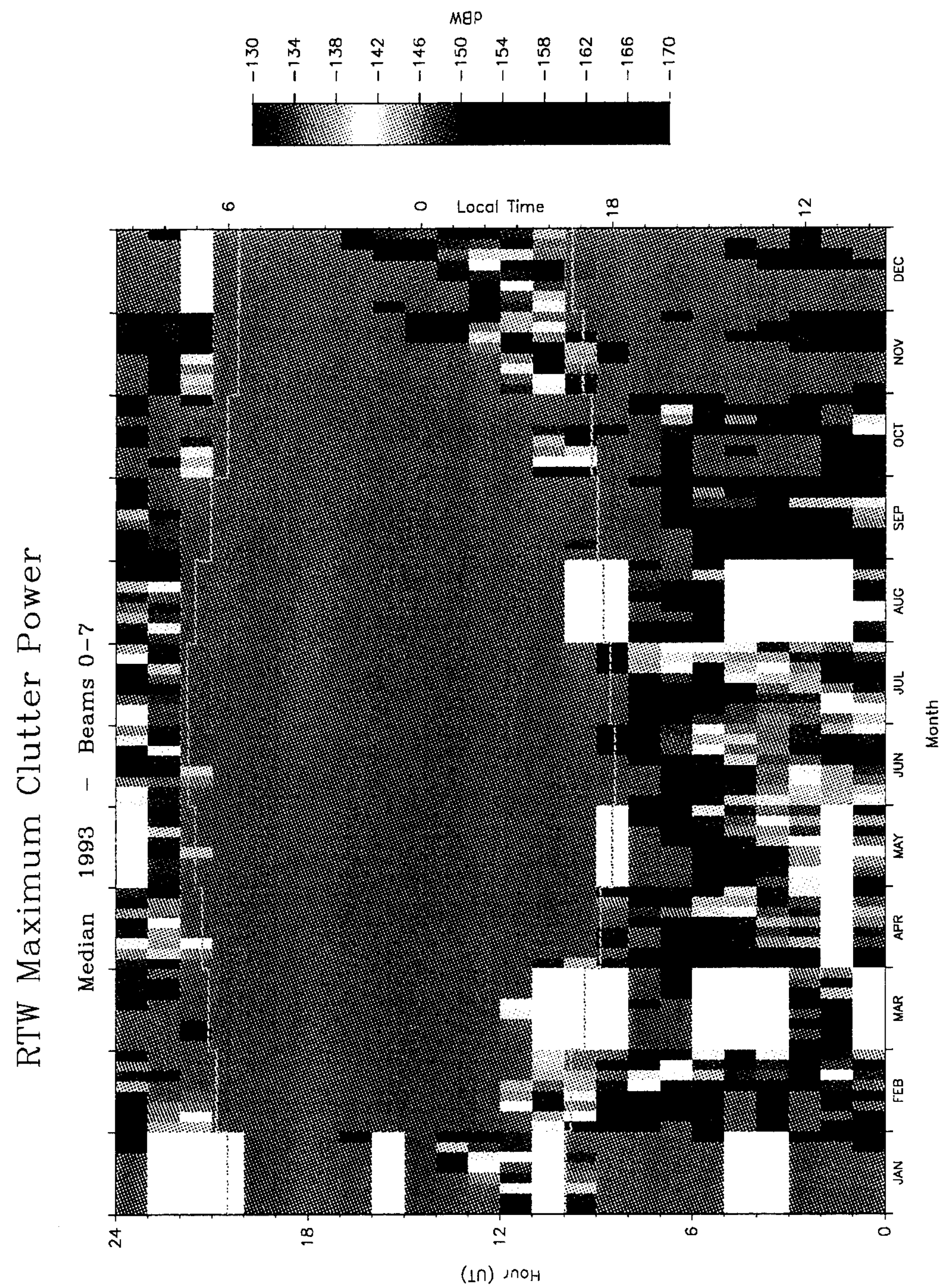


Figure 13: *A plot of the monthly median peak clutter power recorded on all beams during 1993 as a function of time of day. Within each month the values for the beams (0-7, left to right) are plotted. During winter, June-July, RTW propagation occurred exclusively during the daylight hours. In summer, January and December, the strongest returns were measured post-sunset however weaker signals were also detected during the day.*

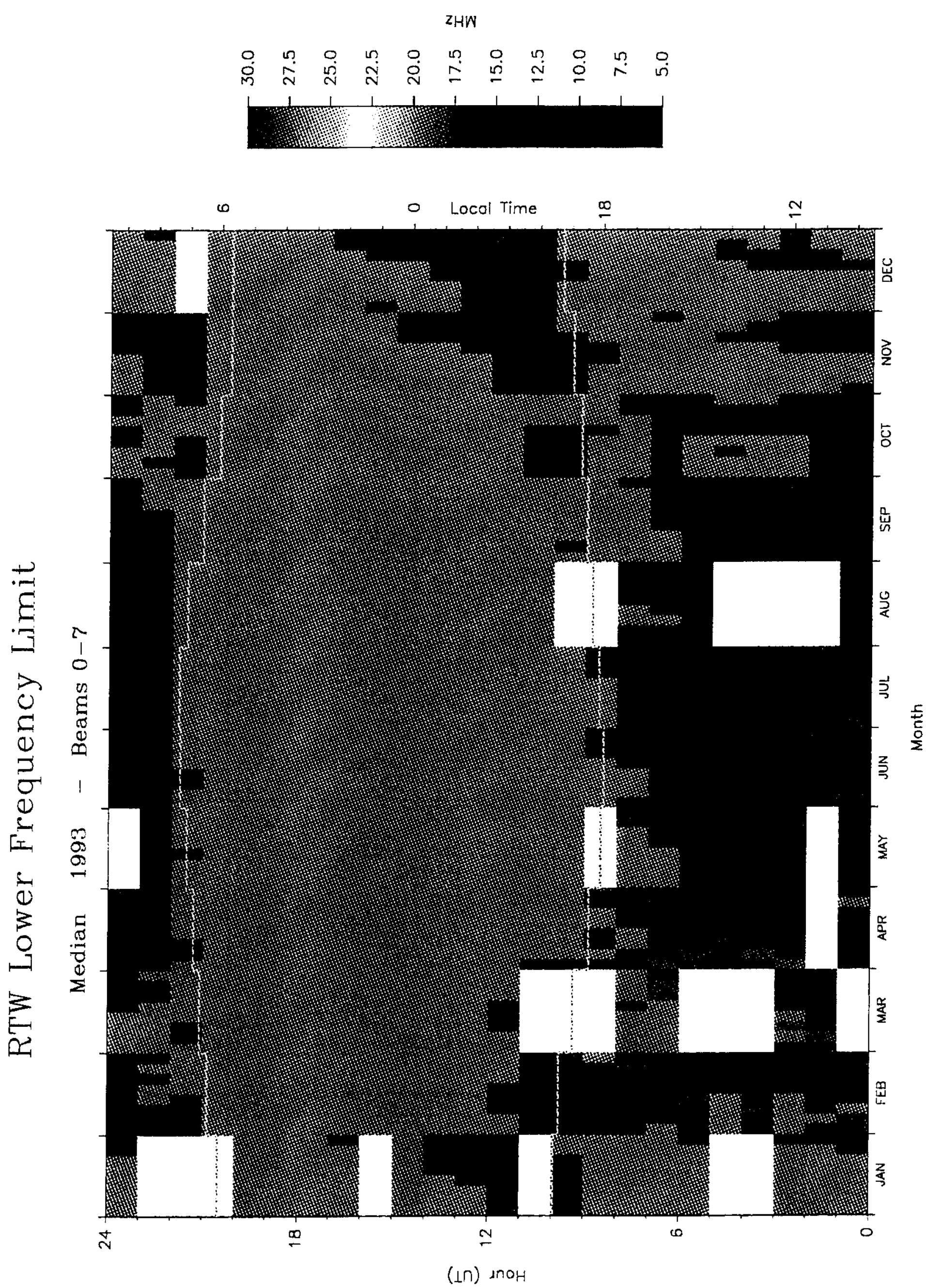


Figure 14: The median lower frequency limit observed for each month in 1993. During the months of optimum propagation, June and December, it commences at 9-10 Mhz. It increases during the subsequent few hours to finish at 16 Mhz. Note the summer daytime propagation behaves similarly to the winter signals. Note also the region of higher frequencies during the autumn equinox.

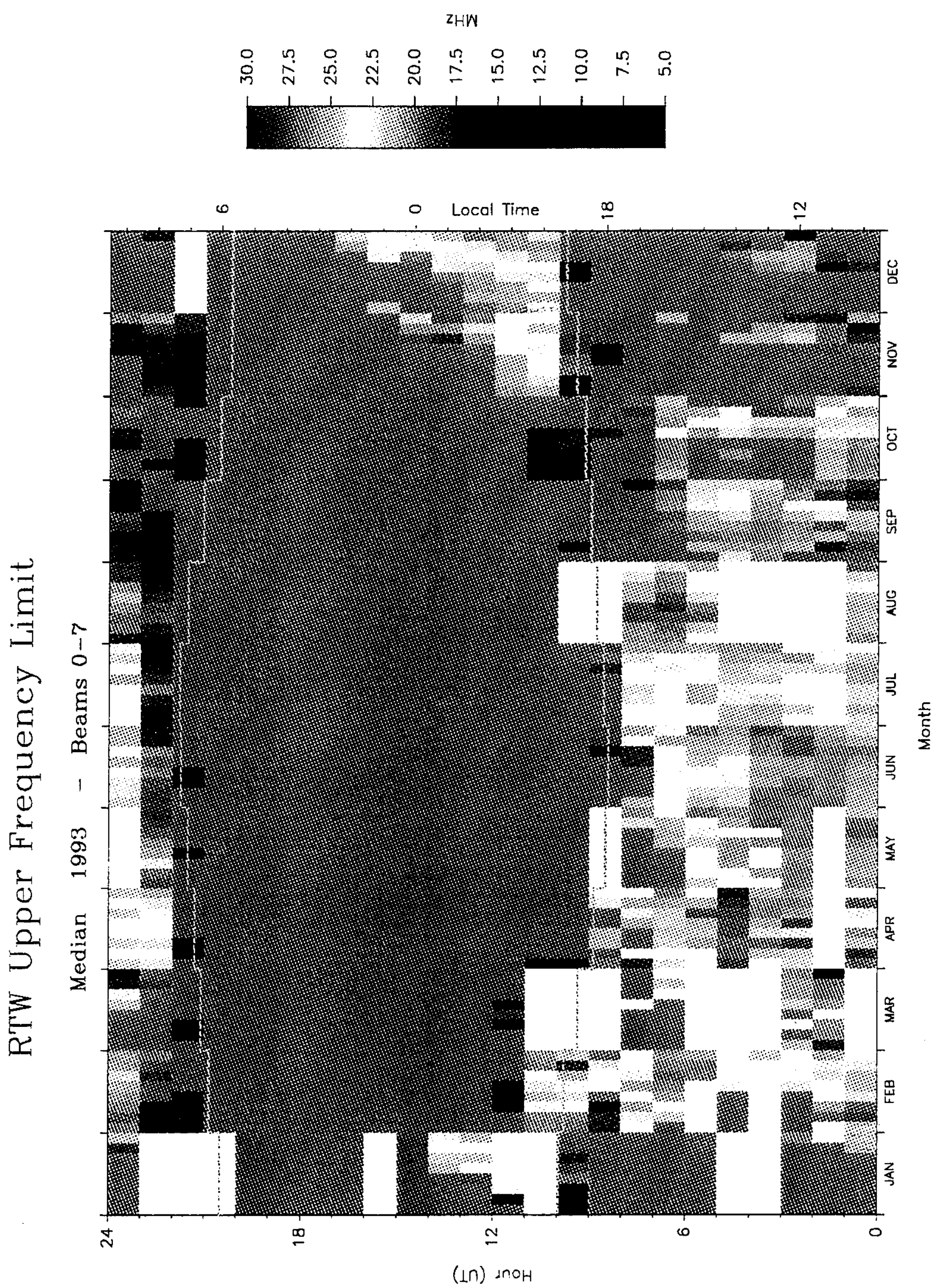


Figure 15: The median upper frequency limit for 1993. The autumn equinox period again shows the highest frequency returns.

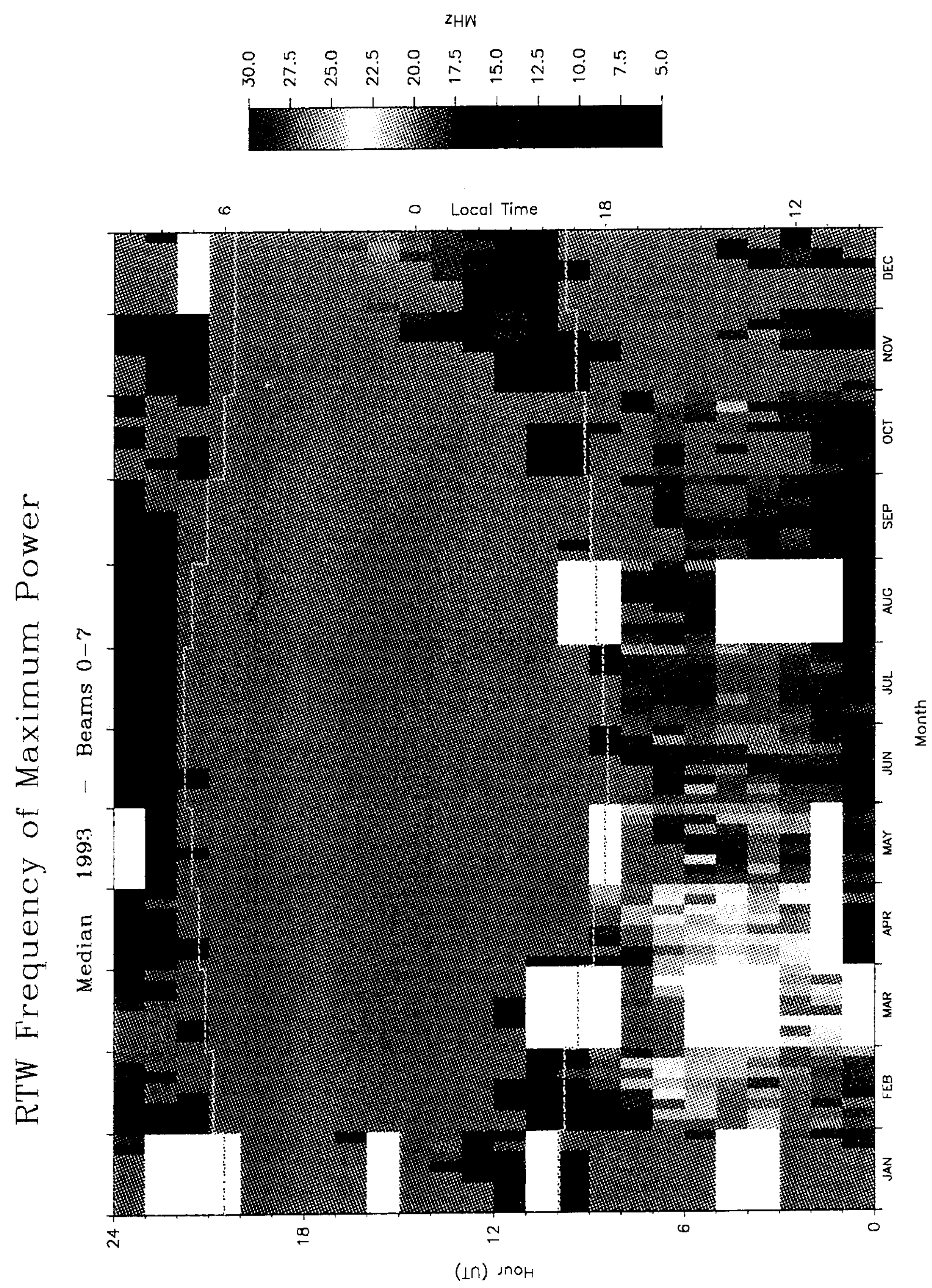


Figure 16: The monthly median of the frequency at which the maximum clutter signal was recorded for 1993.

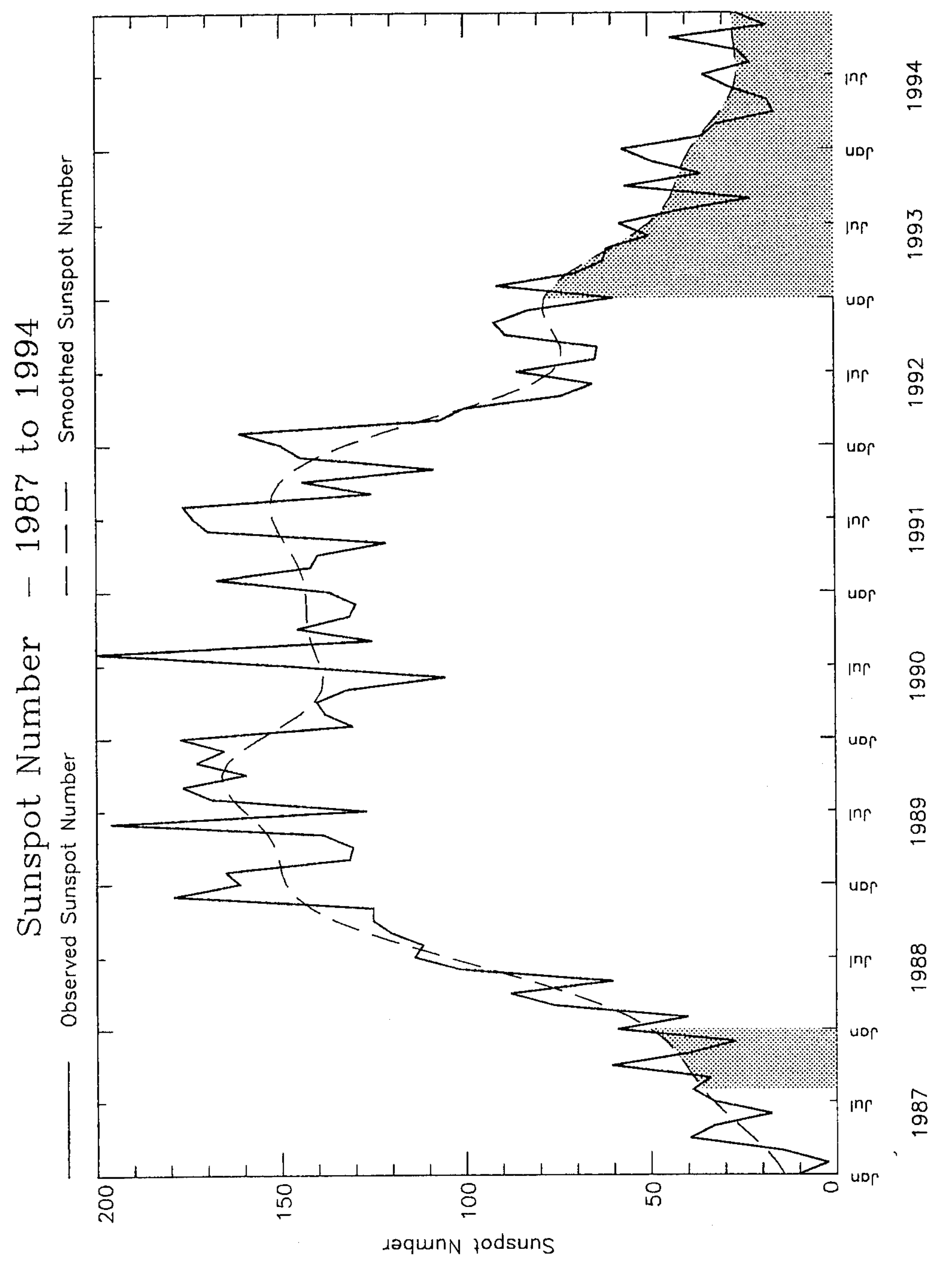


Figure 17: Observed and smoothed sunspot number for the period 1987 to 1994. The shaded regions are those where round-the-world propagation measurements were made.

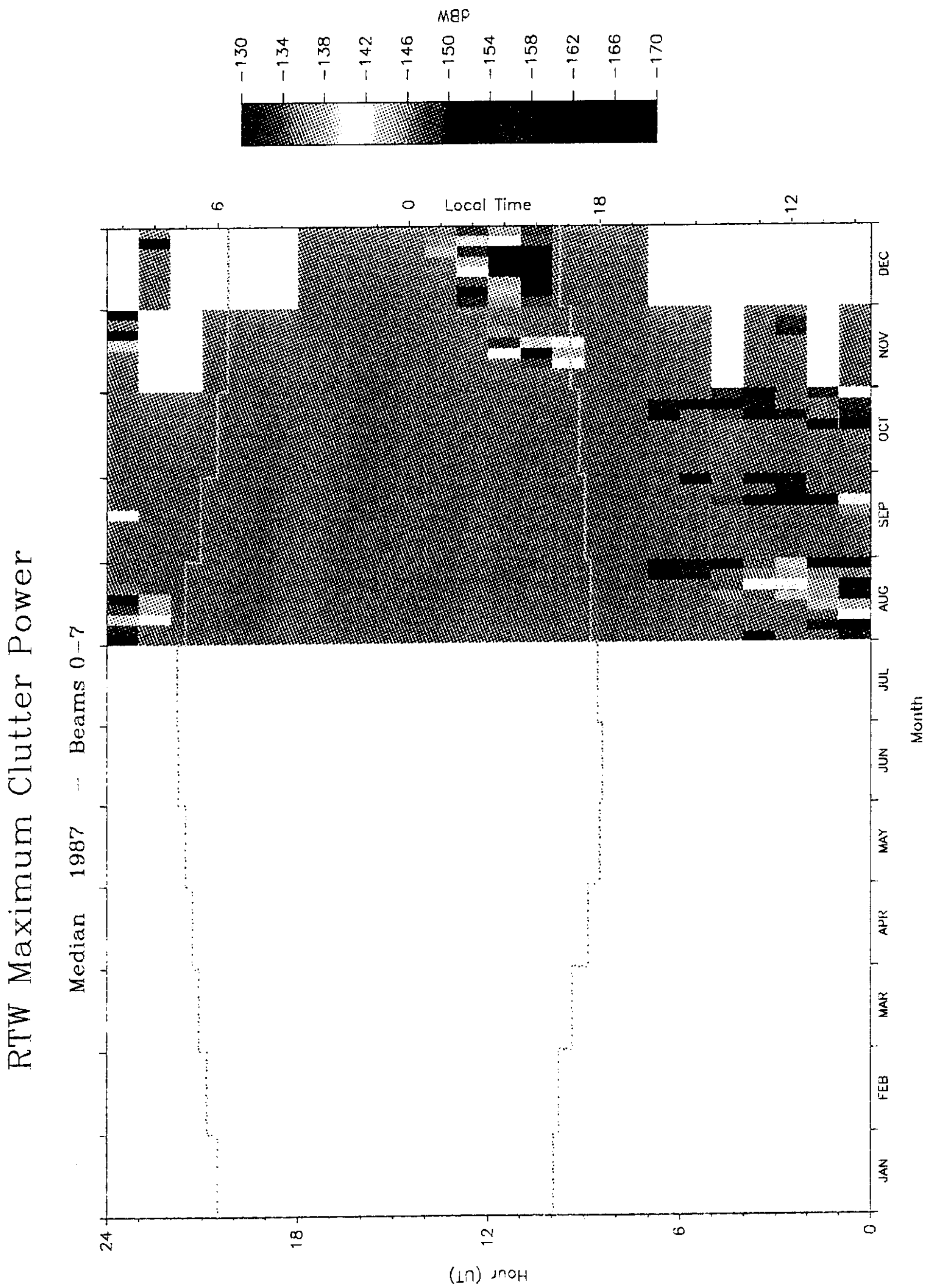


Figure 18: RTW maximum clutter power - the monthly medians for 1987.

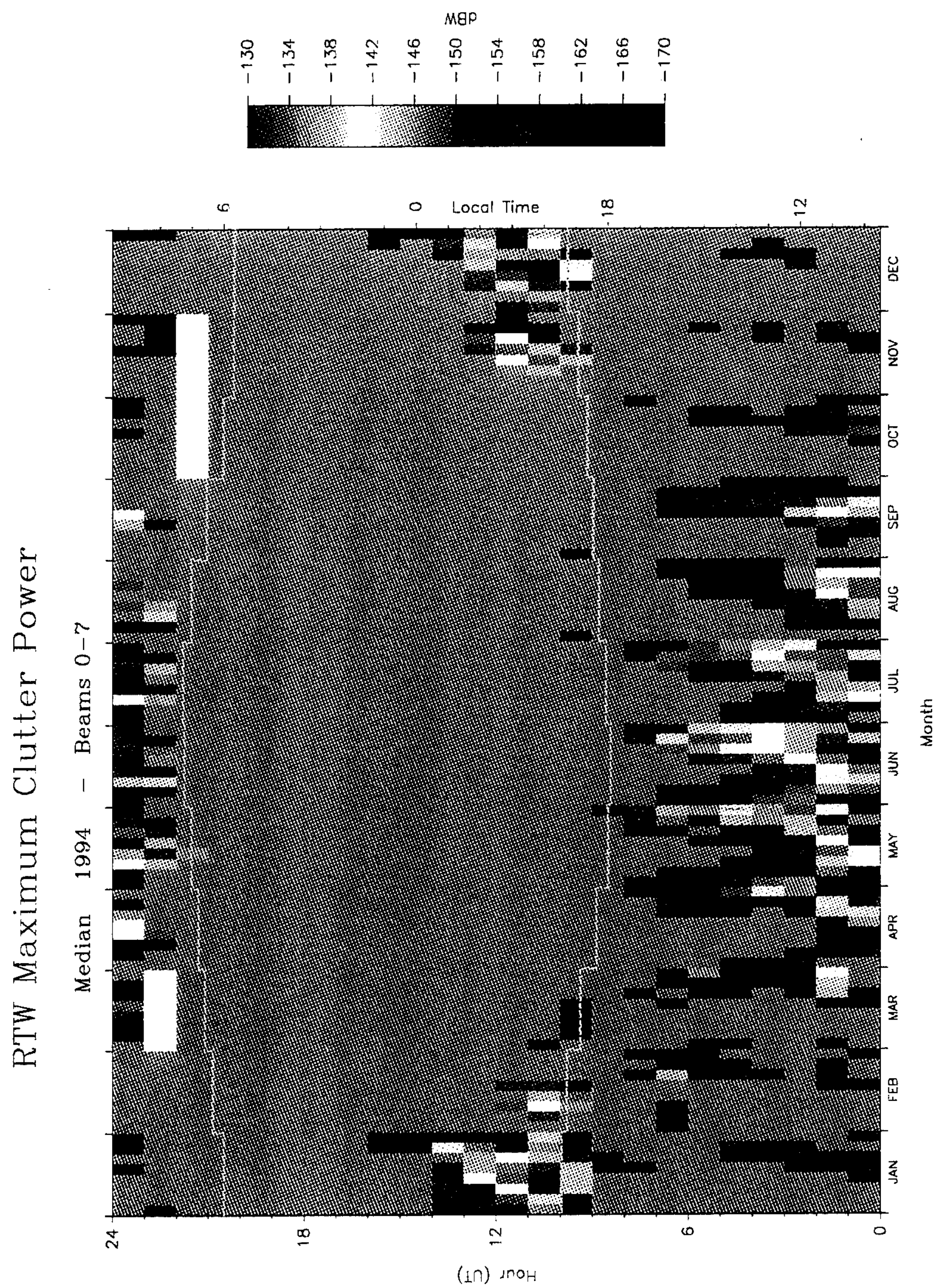


Figure 19: Monthly median RTW maximum clutter power for 1994.

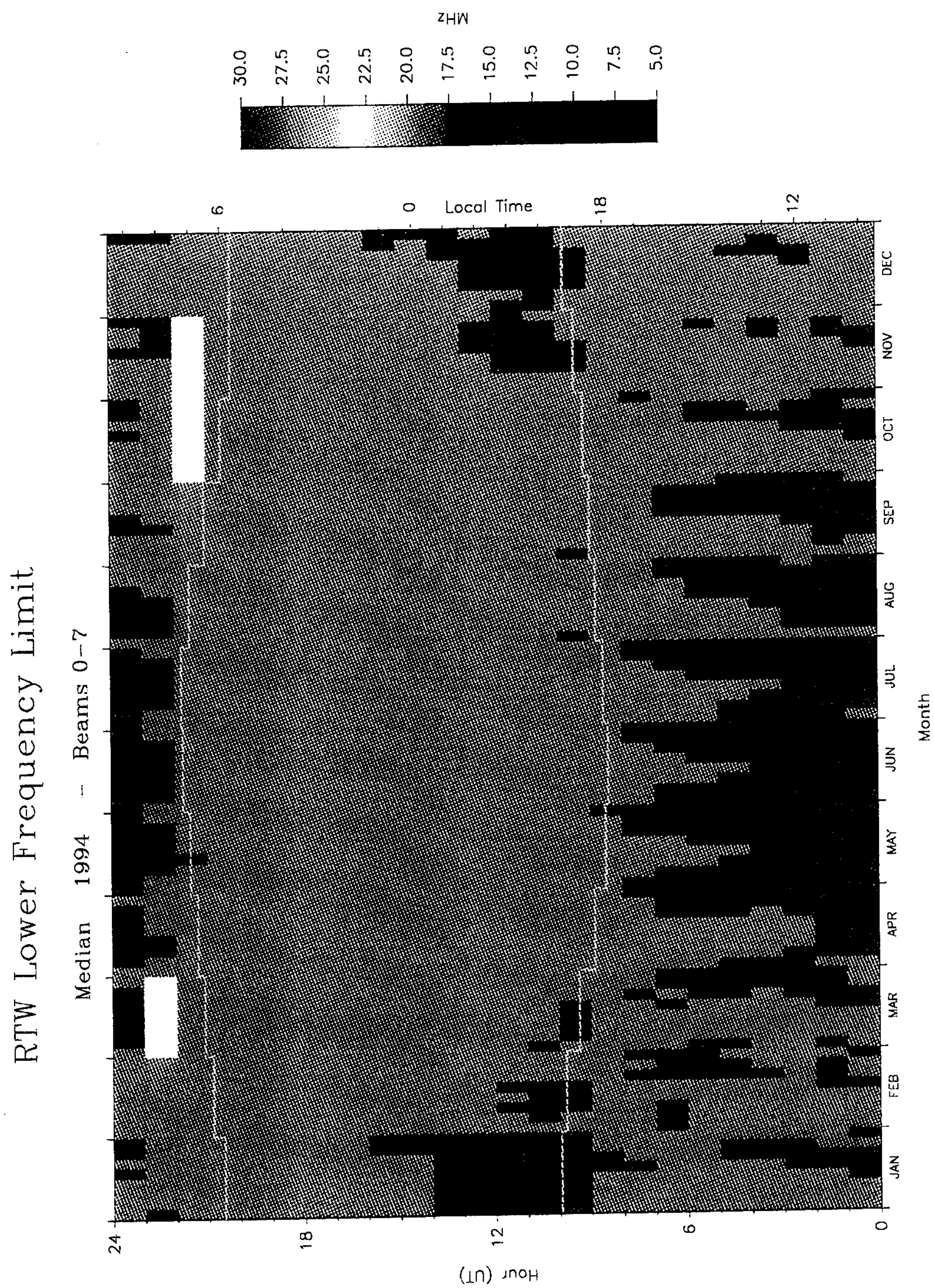


Figure 20: Lower frequency limit of the RTW signals recorded during 1994.

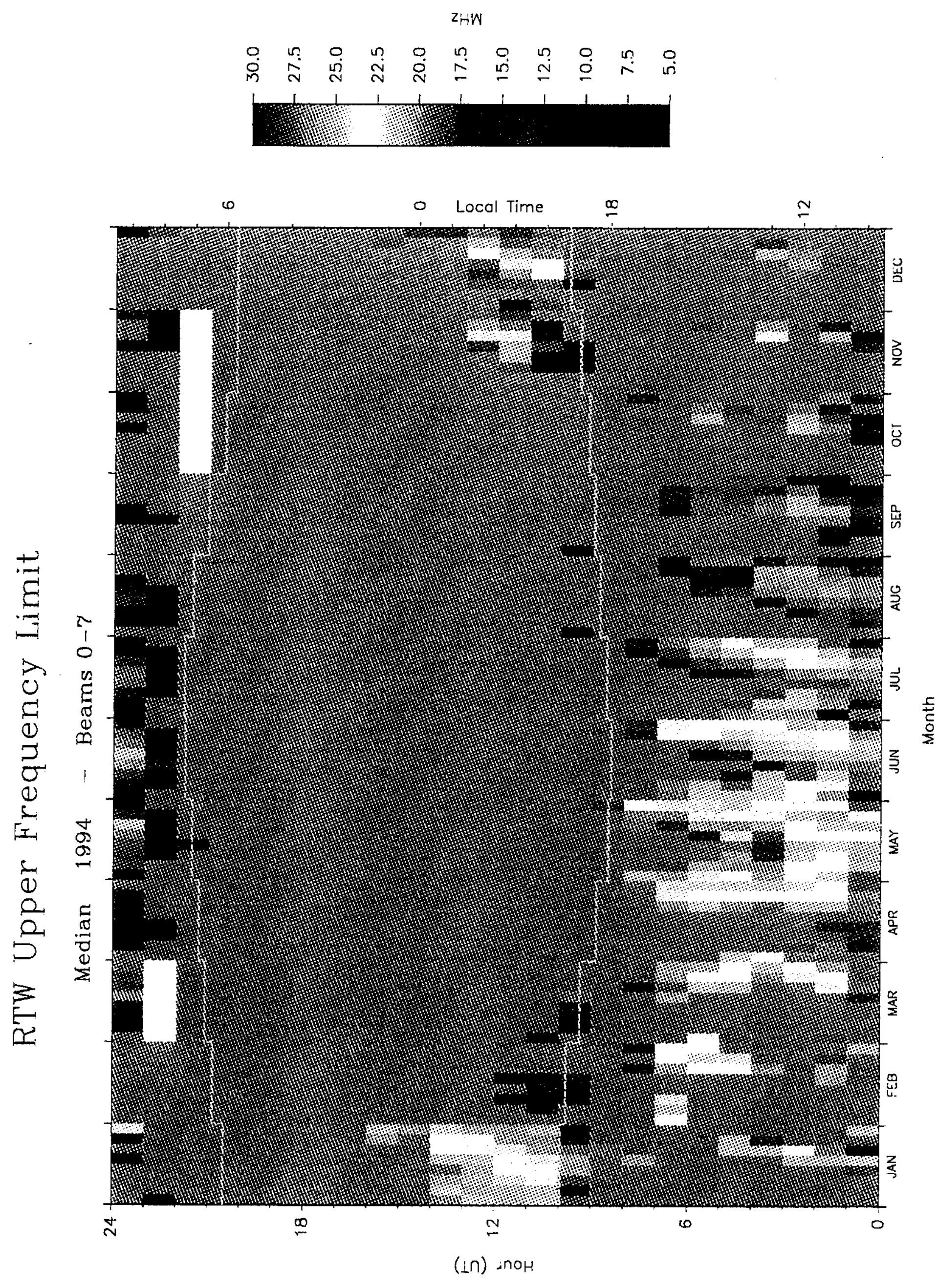


Figure 21: Upper frequency limit of the RTW signals recorded during 1994.

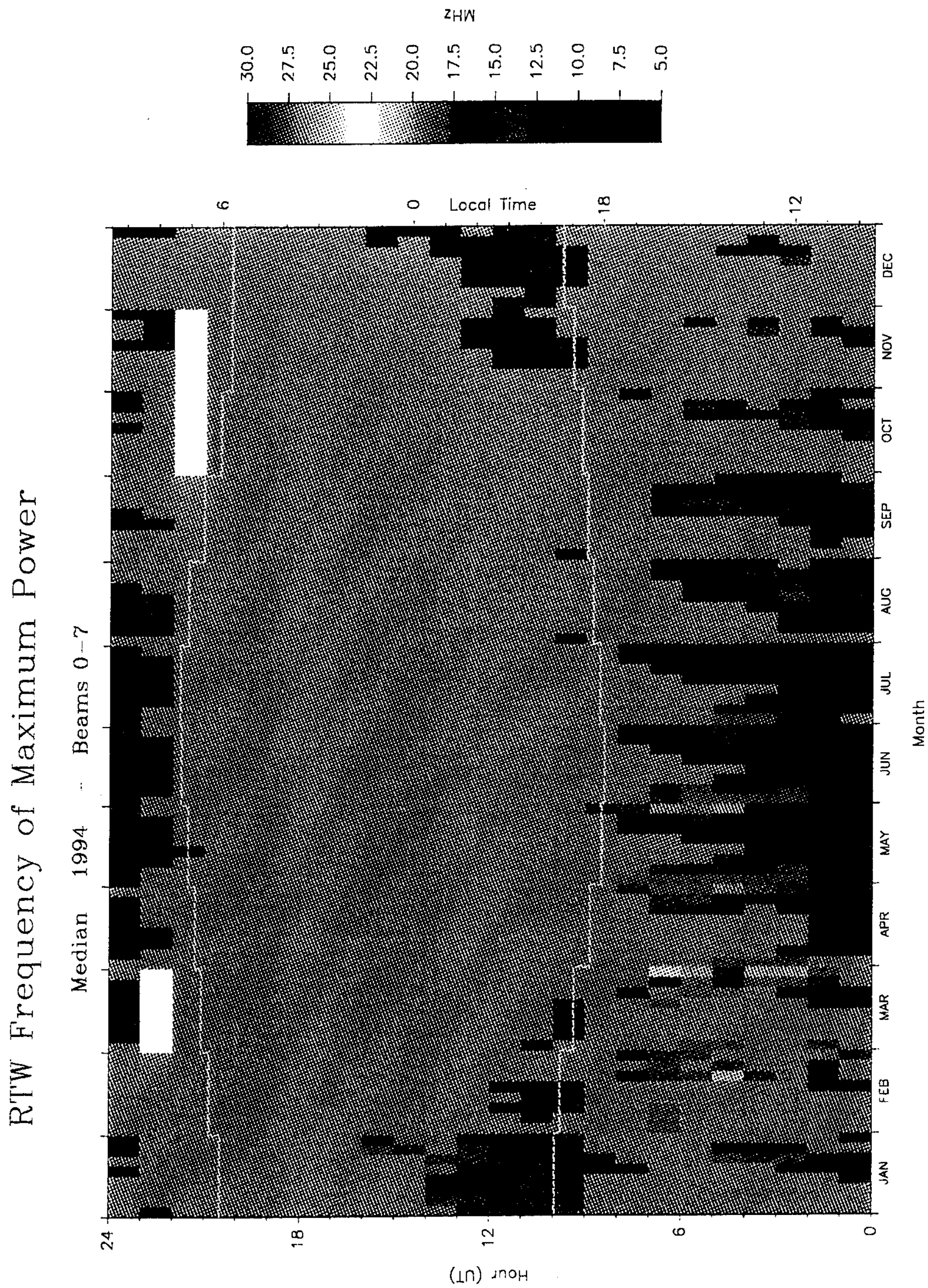


Figure 22: Frequency of the maximum RTW clutter power - median for 1994. The autumn equinox frequency increase seen during 1993 is again visible.

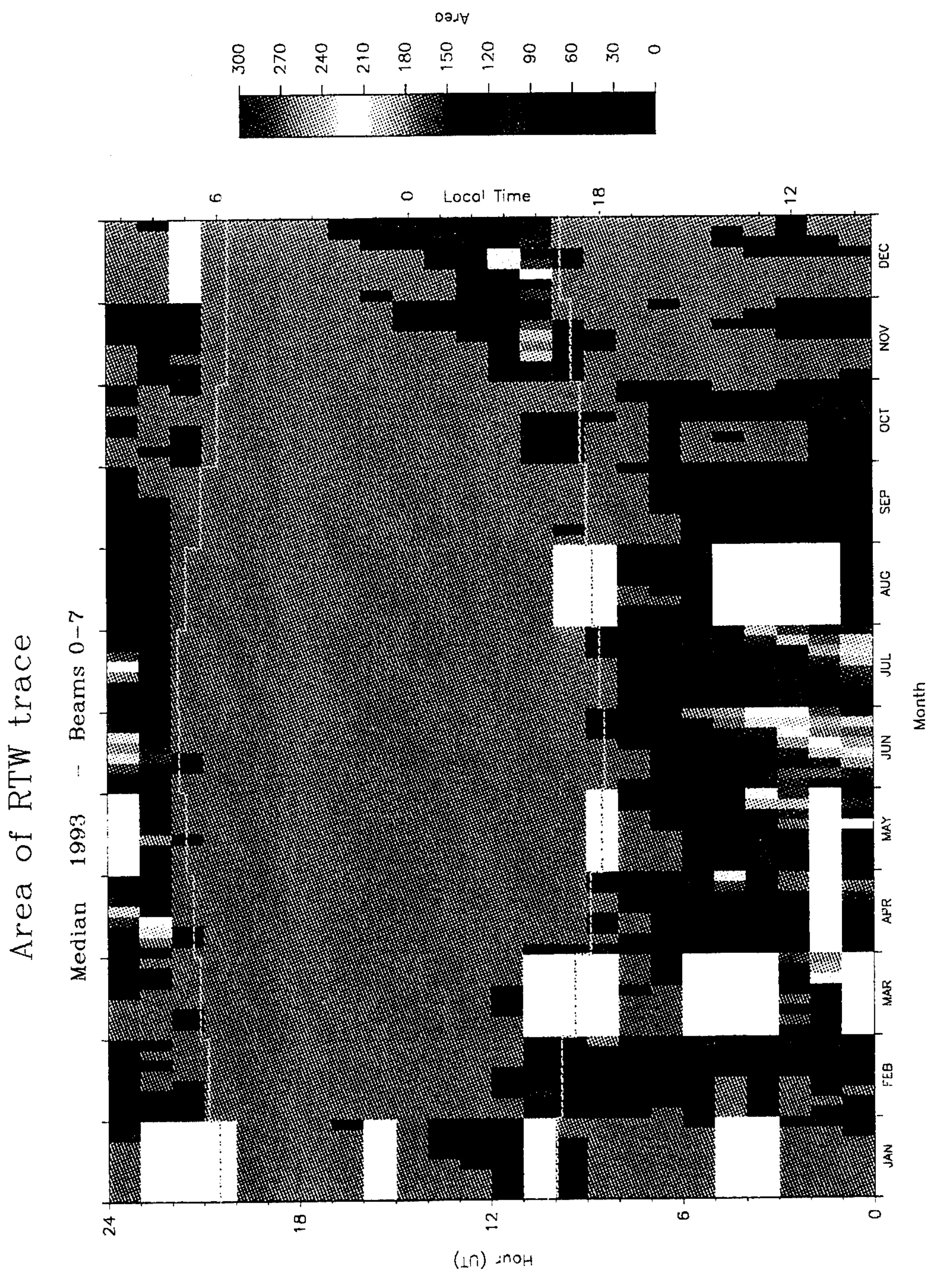


Figure 23: Area of the round-the-world trace, monthly median for 1993.

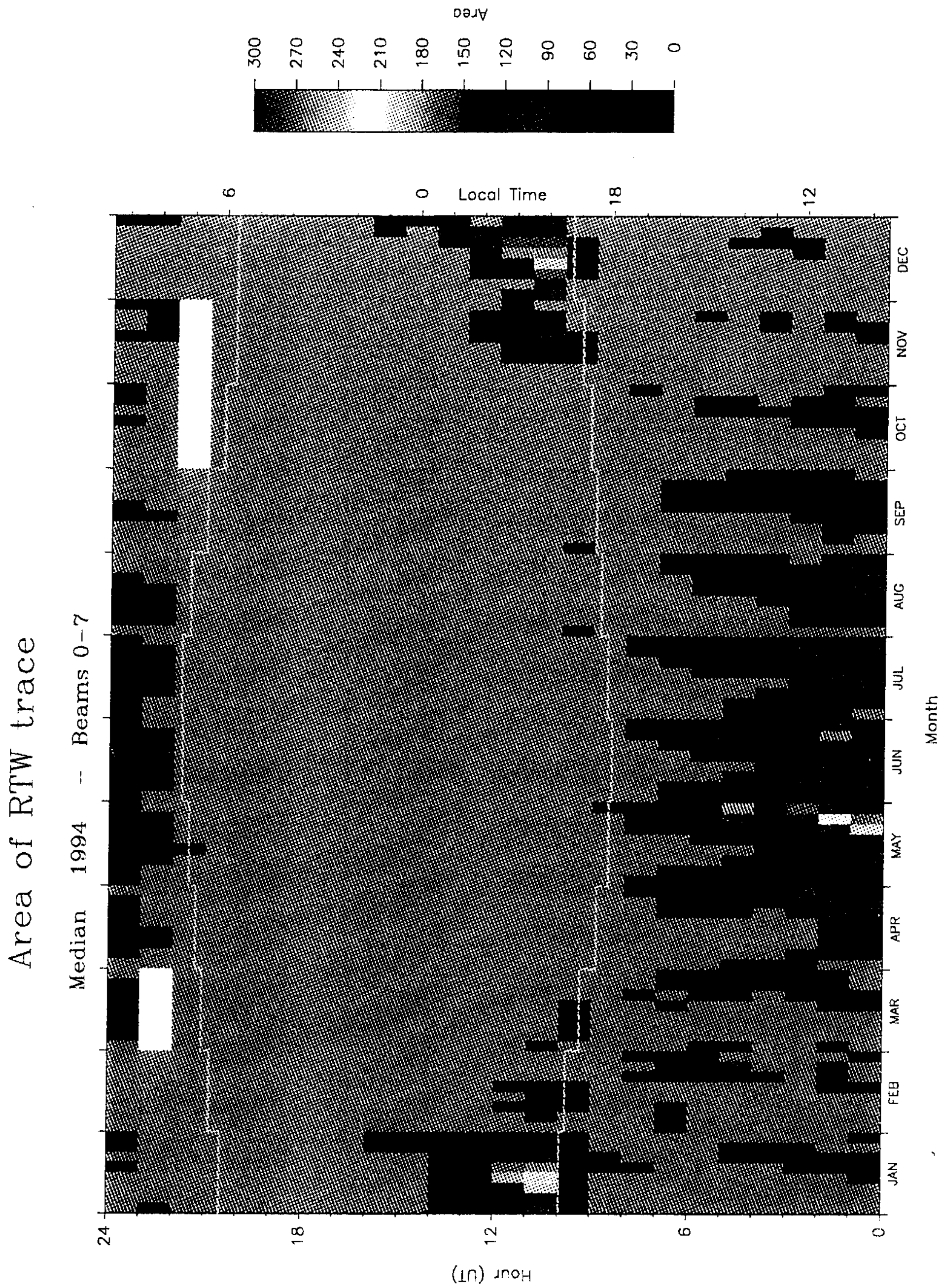


Figure 24: RTW area for 1994 at a median level.

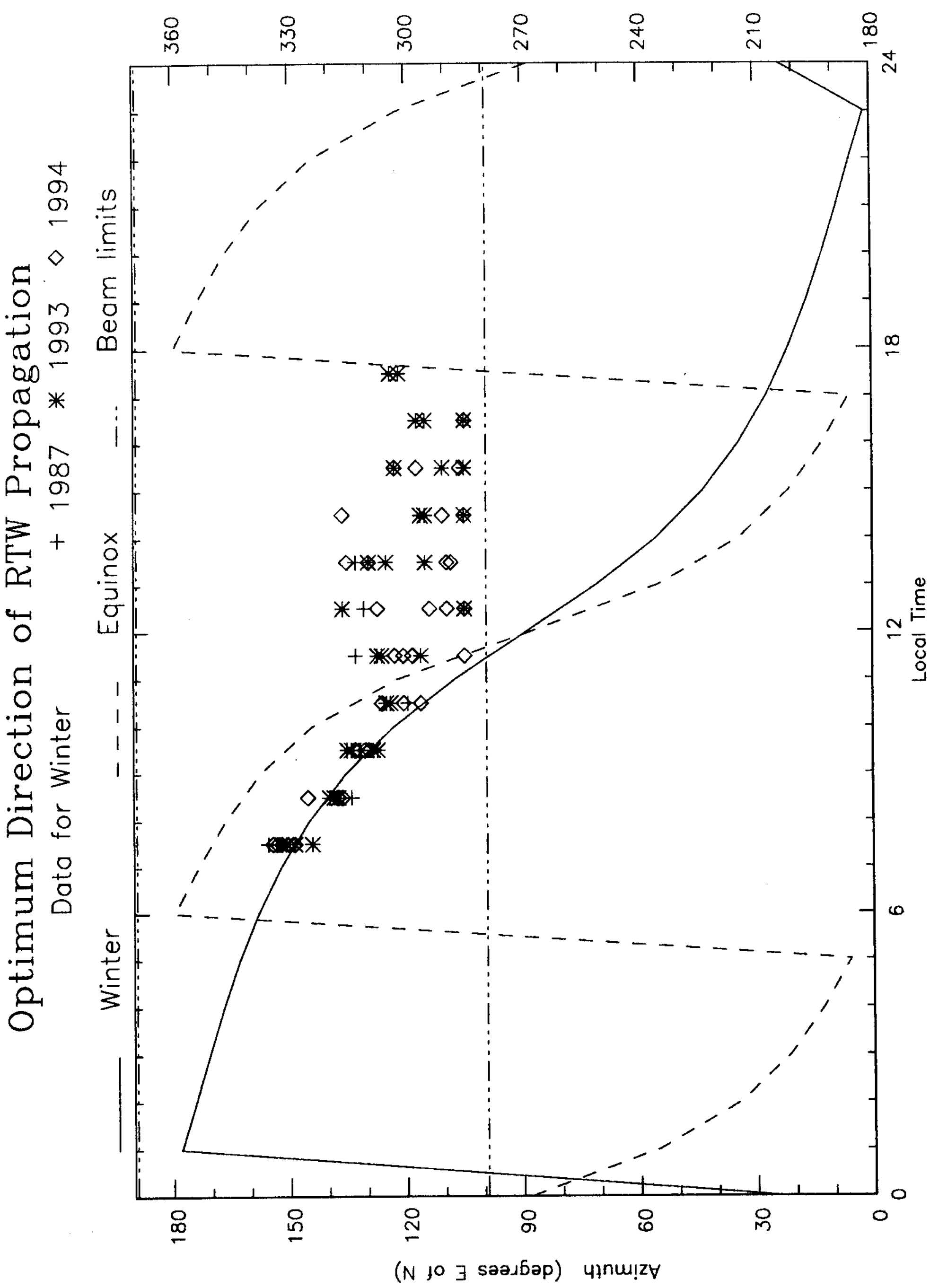


Figure 25: Optimum direction of RTW propagation observed during the winter months (May to August) of 1987, 1993 and 1994. The theoretical optimum azimuths for winter and the equinoxes are also shown. The azimuth limits of the FMS beams are indicated.

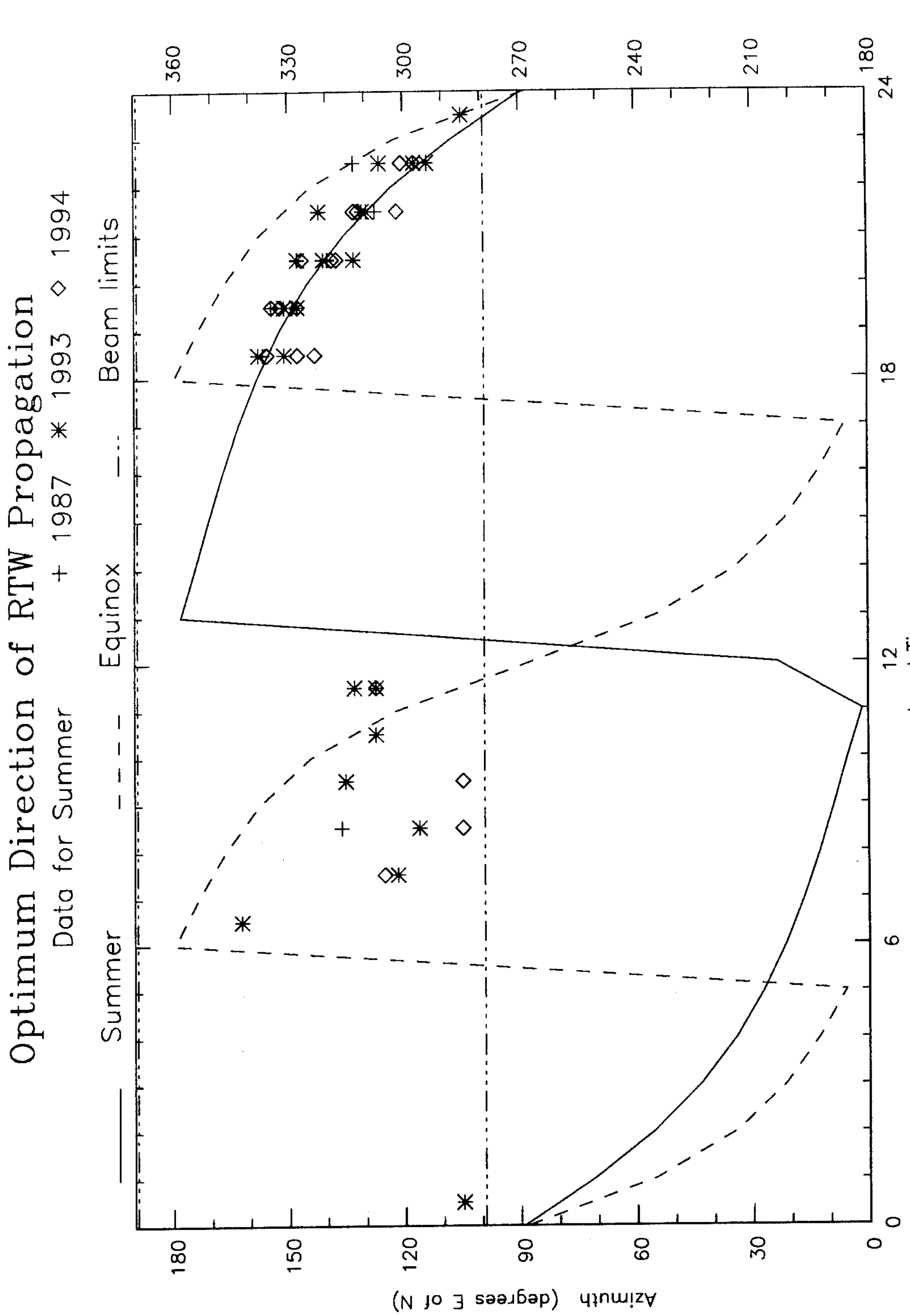


Figure 26: Optimum direction of RTW propagation for the summer months (January, November and December) of 1987, 1993 and 1994

ROUND-THE-WORLD HIGH FREQUENCY PROPAGATION: A SYNOPTIC STUDY

MARK TYLER

DSTO-RR-0059

	No. of copies
DSTO	1 copy
<u>Defence Science and Technology Organisation</u>	
Chief Defence Scientist	1 shared copy
FAS Science Policy	
AS Science Corporate Management	
Director AMRL	1 copy
Counsellor Defence Science, London	Doc Data Sheet
Counsellor Defence Science, Washington	1 copy
Scientific Adviser to Thailand MRD	Doc Data Sheet
Scientific Adviser to the DRC (Kuala Lumpur)	Doc Data Sheet
Senior Defence Scientific Adviser/Scientific Adviser POLCOM	1 shared copy
Navy Scientific Adviser	3 Doc Data Sheet + 1 copy Dist. List
Scientific Adviser - Army	Doc Data Sheet + 1 copy Dist.List
Air Force Scientific Adviser	1 copy
Director Trials	1 copy
<u>Originating Laboratory</u>	
Chief High Frequency Radar Division	1 copy
Research Leader High Frequency	1 copy
Head, Ionospheric Effects	1 copy
Mark Tyler	1 copy
Dr G.F. Earl	1 copy
Dr P.S. Whitham	1 copy
<u>DSTO Library</u>	
DSTO Library Fishermens Bend	1 copy
DSTO Library Maribyrnong	1 copy
DSTO Library Salisbury	2 copies
DSTO Library Pyrmont	Doc Data sheet

Defence Central

OIC TRS, Defence Central Library	1 copy
Officer in Charge, Document Exchange Centre (DEC),	1 copy
DEC requires the following copies of public release reports to meet exchange agreements under their management:	
*US Defence Technical Information Centre,	2 copies
*UK Defence Research Information Centre,	2 copies
*Canada Defence Scientific Information Service,	1 copy
*NZ Defence Information Centre,	1 copy
National Library of Australia,	1 copy
The Director, Qinghua University, Beijing,	1 copy
The Librarian, Beijing University of Aeronautics,	1 copy
The Librarian, Institute of Mechanics, Chinese Academy of Sciences	1 copy
Defence Intelligence Organisation	1 copy
Defence Signals Directorate, Library	Doc Data Sheet

Air Force

OIC ATF ATS, RAAFSTT, WAGGA	2 copies

Army

Director General Force Development (Land),	1 copy
ABCA Office, G-1-34, Russell Offices, Canberra	4 copies
SO (Science), HQ 1 Division, Milpo, Enoggera, Qld 4057	Doc Data Sheet
NAPOC QWG Engineer NBCD c/- DENGRS-A, HQ Engineer Centre, Liverpool Military Area, NSW 2174	Doc Data Sheet

Navy

Director General Force Development (Sea)	1 copy
SO (Science), Director of Naval Warfare, Maritime HQ Annex, Garden Island, NSW 2000	Doc Data Sheet

UNIVERSITIES AND COLLEGES

Australian Defence Force Academy	
- Library	1 copy
- Head of Aerospace and Mechanical Engineering	1 copy
Deakin University, Serials Section (M list)), Deakin University Library, Geelong, 3217,	1 copy
Senior Librarian, Hargrave Library, Monash University	1 copy

OTHER ORGANISATIONS

NASA (Canberra)	1 copy
AGPS	1 copy
State Library of South Australia	1 copy
Parliamentary Library, South Australia	1 copy

ABSTRACTING AND INFORMATION ORGANISATIONS

INSPEC: Acquisitions Section Institution of Electrical Engineers	1 copy
Library, Chemical Abstracts Reference Service	1 copy
Engineering Societies Library, US	1 copy
American Society for Metals	1 copy
Documents Librarian, The Center for Research Libraries, US	1 copy

INFORMATION EXCHANGE AGREEMENT PARTNERS

Acquisitions Unit, Science Reference and Information Service, UK	1 copy
Library - Exchange Desk, National Institute of Standards and Technology, US	1 copy
National Aerospace Laboratory, Japan	1 copy
National Aerospace Laboratory, Netherlands	1 copy

SPARES

DSTO Library Salisbury	10 copies

THIS PAGE INTENTIONALLY BLANK

1. Page Classification
UNCLASSIFIED
2. Privacy Marking/Caveat (of document)

Department of Defence

DOCUMENT CONTROL DATA SHEET

3a. AR Number	3b. Laboratory Number	3c. Type of Report	4. Task Number
AR-009-421	DSTO-RR-0059	Research Report	DST 91/027

5. Document Date	6. Cost Code	7. Security Classification	8. No of Pages	9. No of Refs
September 1995	440	* U (Document) U (Title) U (Abstract)	46	12

S (Secret) C (Confi) R (Rest) U (Unclas

* For UNCLASSIFIED docs with a secondary distribution LIMITATION, use (L) in document box.

10. Title

Round-the-World High Frequency Propagation: A Synoptic Study

11. Author(s)
Mark A. Tyler

12. Downgrading/Delimiting Instructions

N/A

13a. Corporate Author and Address

Electronics & Surveillance Research Laboratory
PO Box 1500, Salisbury SA 5108

14. Officer/Position responsible for

Security: ....SOESRL...

Downgrading: ....N/A..

Approval for Release: ....CHFRD.....................................

13b. Task Sponsor
DSTO

15. Secondary Release Statement of this Document
Approved for Public Release

16a. Deliberate Announcement

No Limitations

16b. Casual Announcement (for citation in other documents)

[X] No Limitation [ ] Ref. by Author, Doc No. and date only

17. DEFTEST Descriptors
High Frequency Radar
Diurnal Variations
Backscatter Ionograms
Radiowave Propogation

18. DISCAT Subject Codes

19. Abstract
This Report presents the results of a synoptic study of the propagation characteristics of round-the-world (RTW) high frequency radio signals. The observations were made near Alice Springs using a backscatter sounder. The diurnal, seasonal and solar cycle variations in the signal power and frequency limits are discussed. The measured optimum direction of propagation is determined and compared to a simple model.